

From the west African monsoon up to planetary climate change: synergy between Earth radiation budget measurements

Richard P. Allan

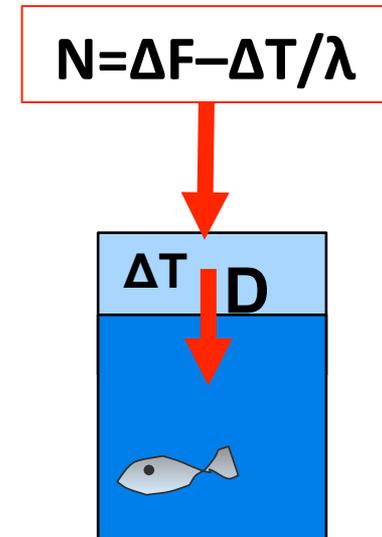
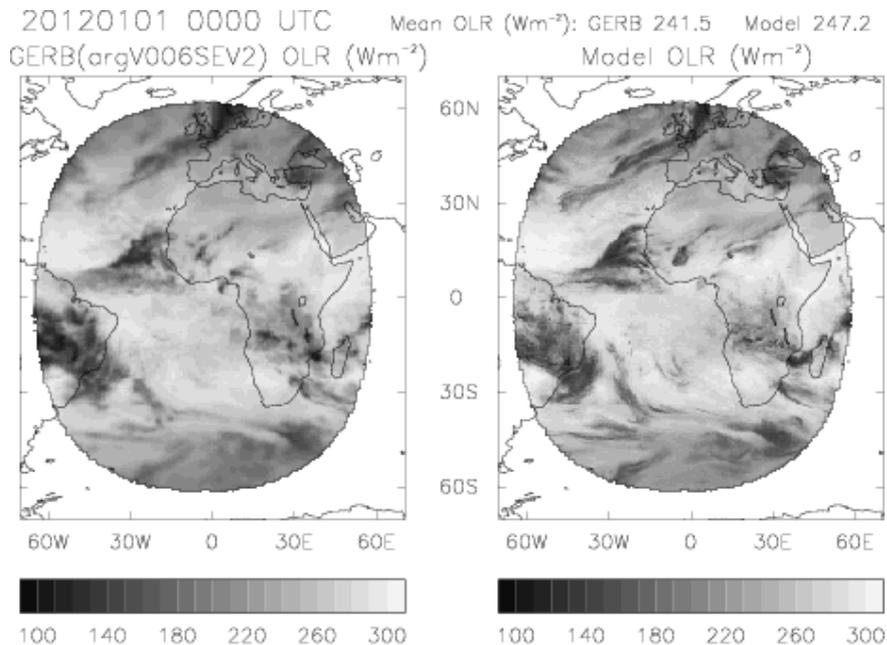
Thanks: Chunlei Liu, Norman Loeb

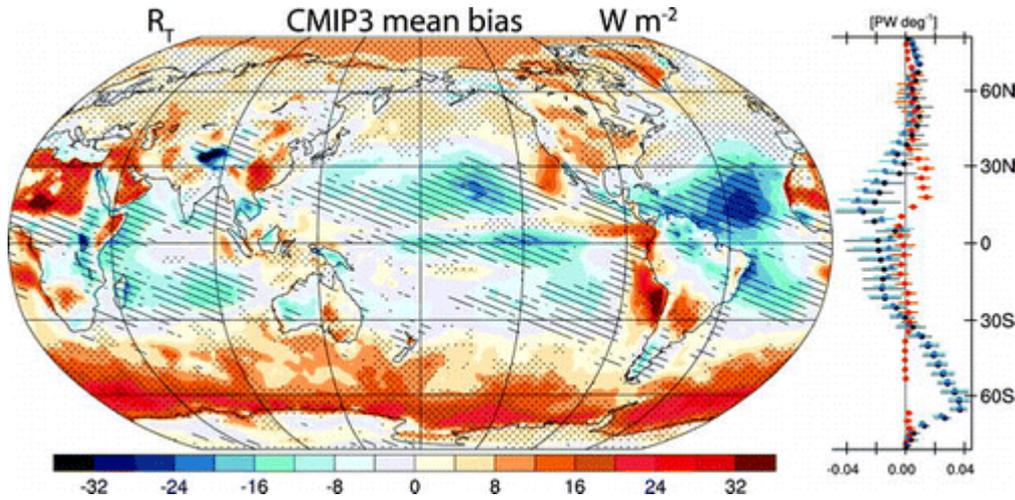
r.p.allan@reading.ac.uk @rpallanuk

*Joint CERES-GERB and SCARAB Earth Radiation Budget workshop
7-10 Oct 2014 Toulouse (France)*

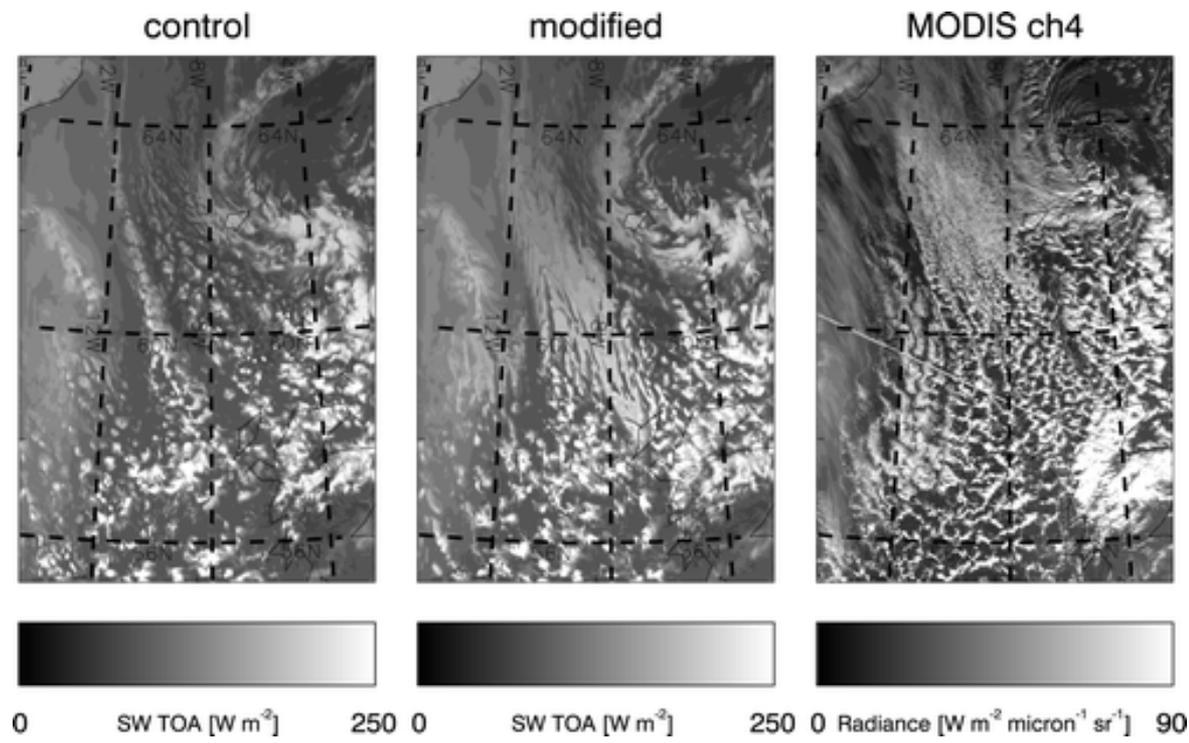
Earth's Energy budget: a key variable...

- Evaluation of weather and climate model processes
- Radiative forcing/feedbacks and ocean heat uptake
- Coupling of global energy and water cycle





Systematic cloud radiative model biases

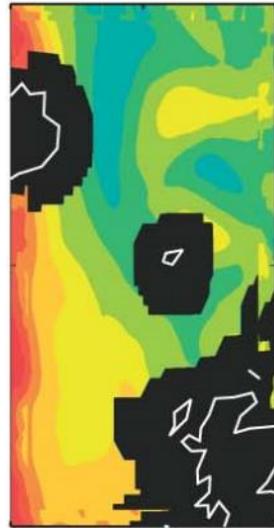


Systematic model biases in cloud radiative forcing relating to cold air outbreaks (e.g. [Trenberth & Fasullo, 2010](#); [Karlsson & Svensson, 2011](#); [Bodas-Salcedo *et al.*, 2012](#))

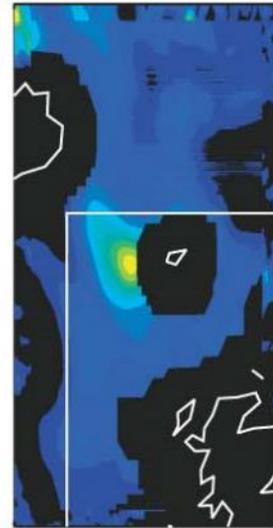
Evaluating model cloud processes

Right: combining AMSR and CERES satellite data to evaluate simulations of a cold air outbreak: [Field et al. \(2014\)](#) [QJRMS](#)

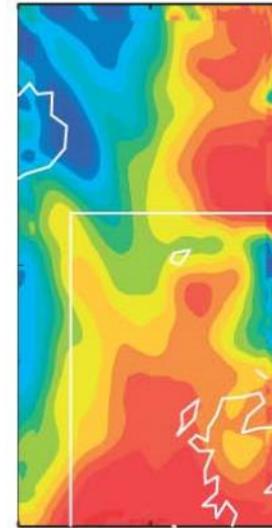
(a) AMSR WWP 12:55



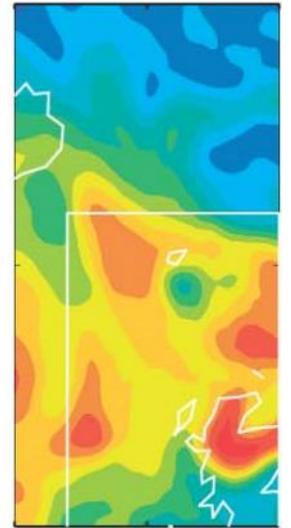
(b) AMSR LWP 12:55



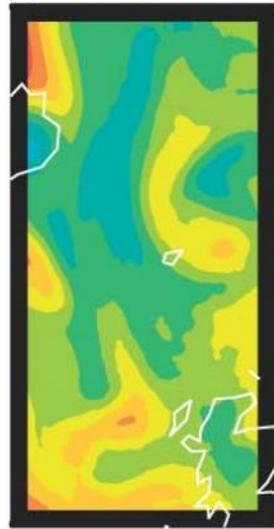
(c) CERES LW 12:48



(d) CERES SW 12:48



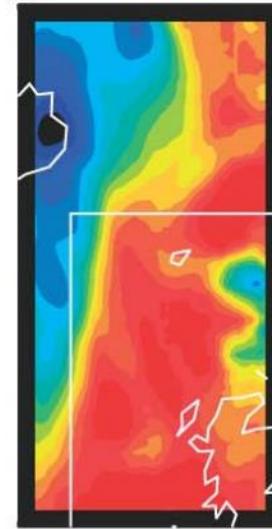
(e) Model WWP 11:00



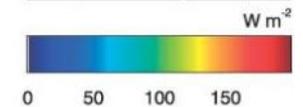
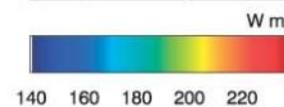
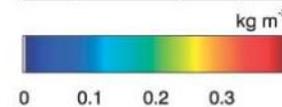
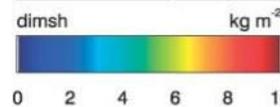
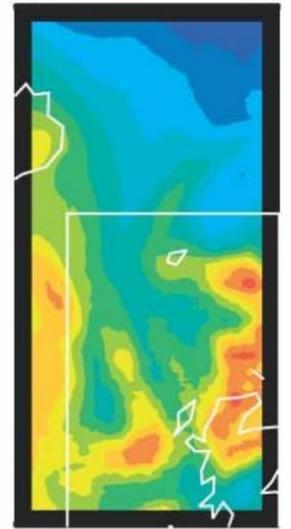
(f) Model LWP 11:00



(g) Model LW 13:00

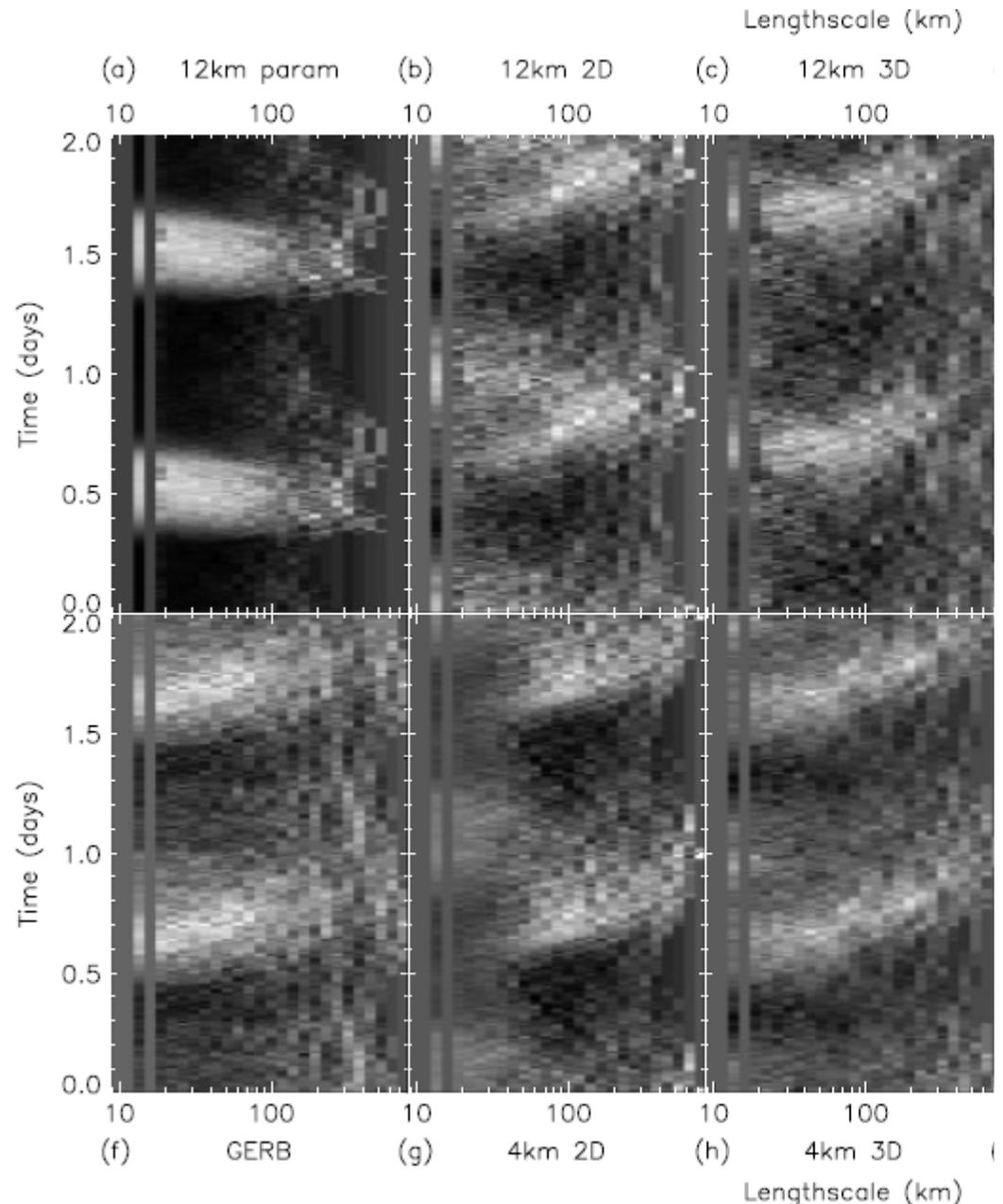


(h) Model SW 13:00



Evaluating diurnal cycle of convection in models

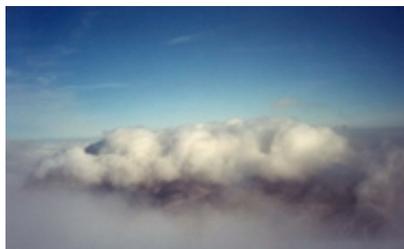
Right: Use of GERB in evaluating simulation of diurnal cycle of convection over W. Africa in the “grey zone” of convective parametrization (4-12km)





Convective outflow

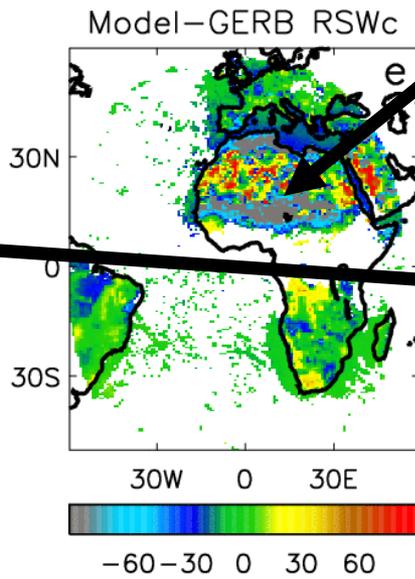
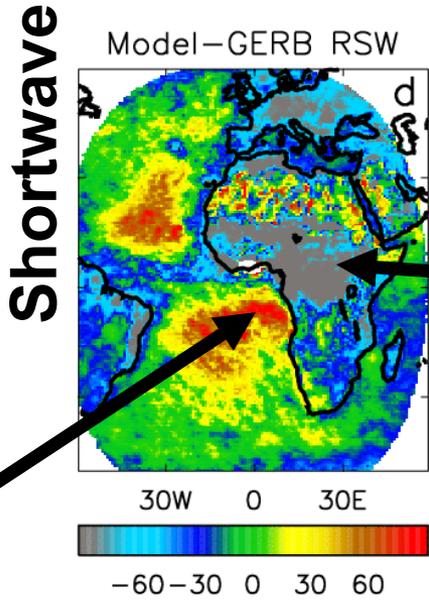
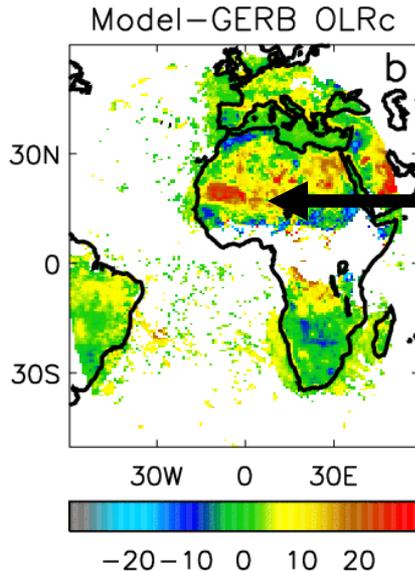
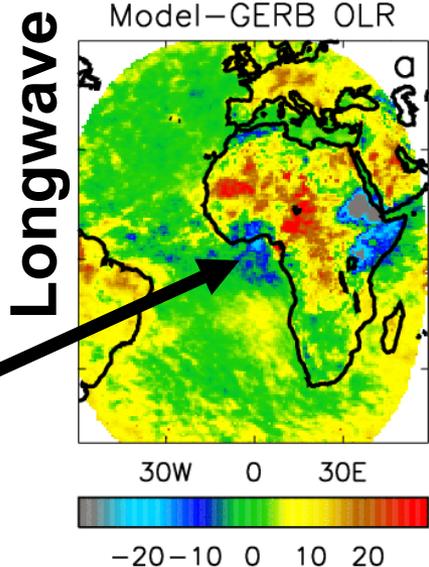
Improving model physics using GERB data



Marine stratocumulus

All-sky

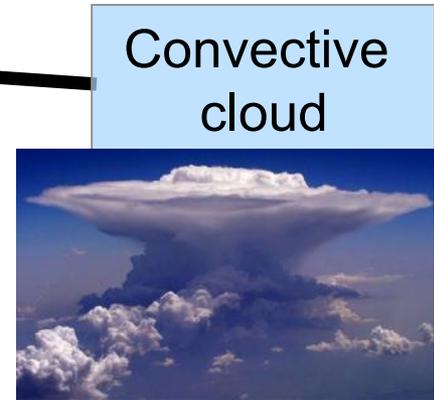
Clear-sky



Mineral dust

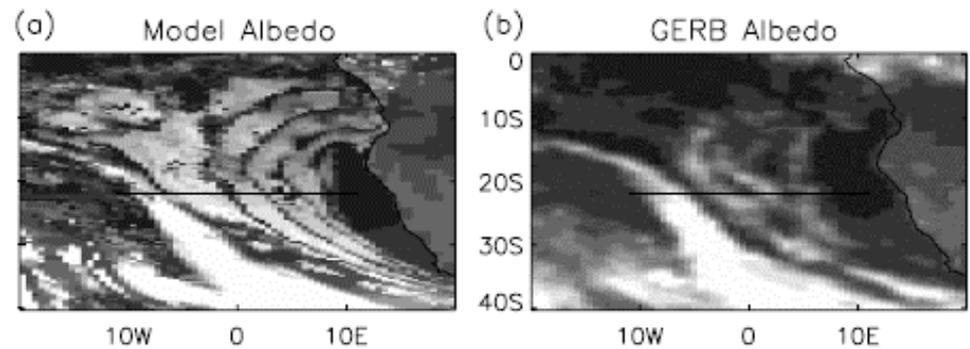


Surface albedo



Convective cloud

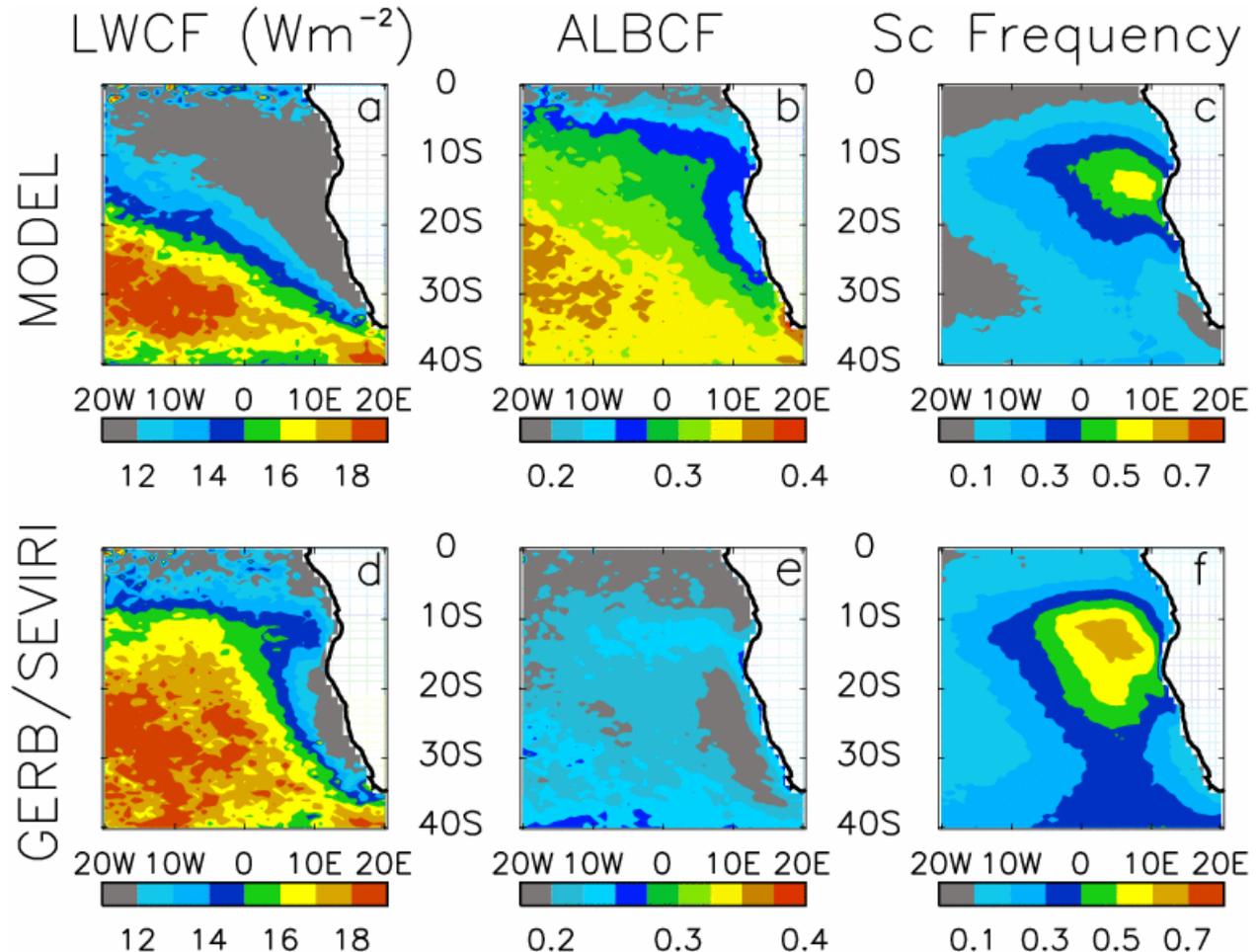
NWP model cloud radiative bias



- LW cloud effect too small by about 5 Wm^{-2}
- SW cloud effect too large...
- ...yet too little stratocumulus cloud cover
- Too few too bright e.g.

[Nam et al. \(2012\)](#)

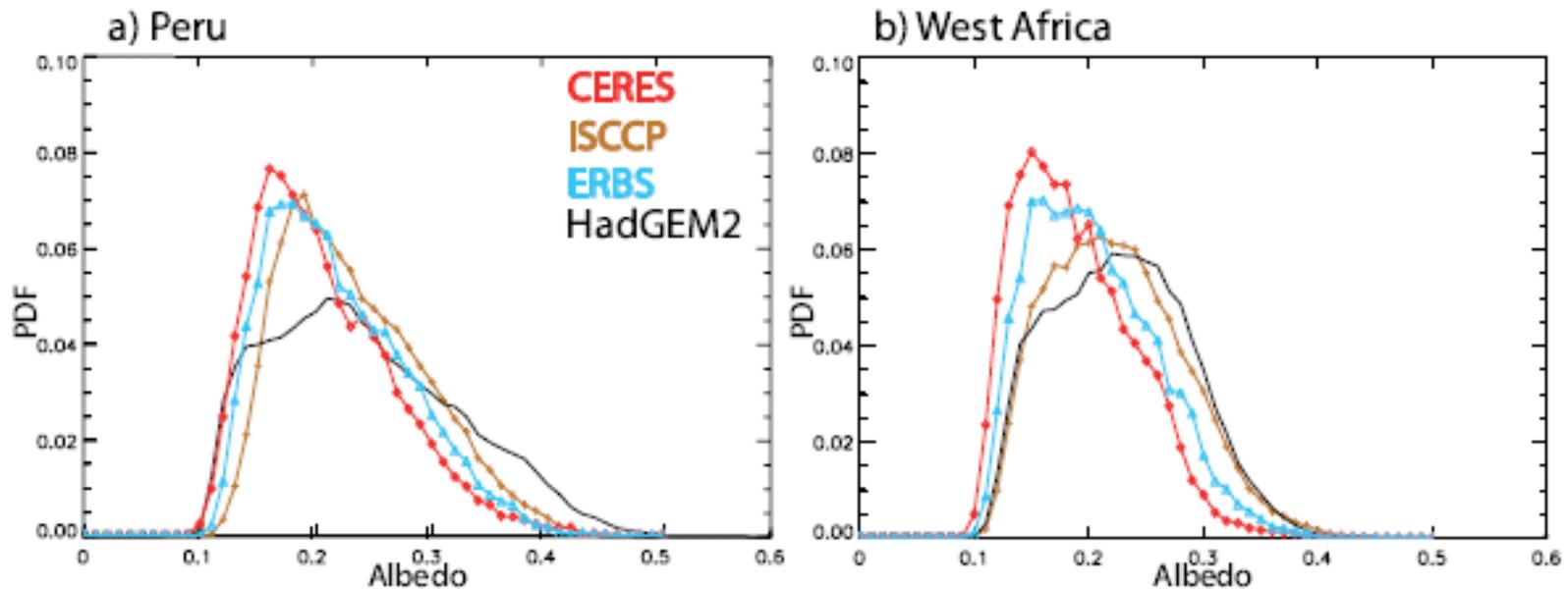
[GRL](#)



Overcast Sc-cover pixels only (2003-2010)

[Allan et al. \(2007\) QJRMS](#)

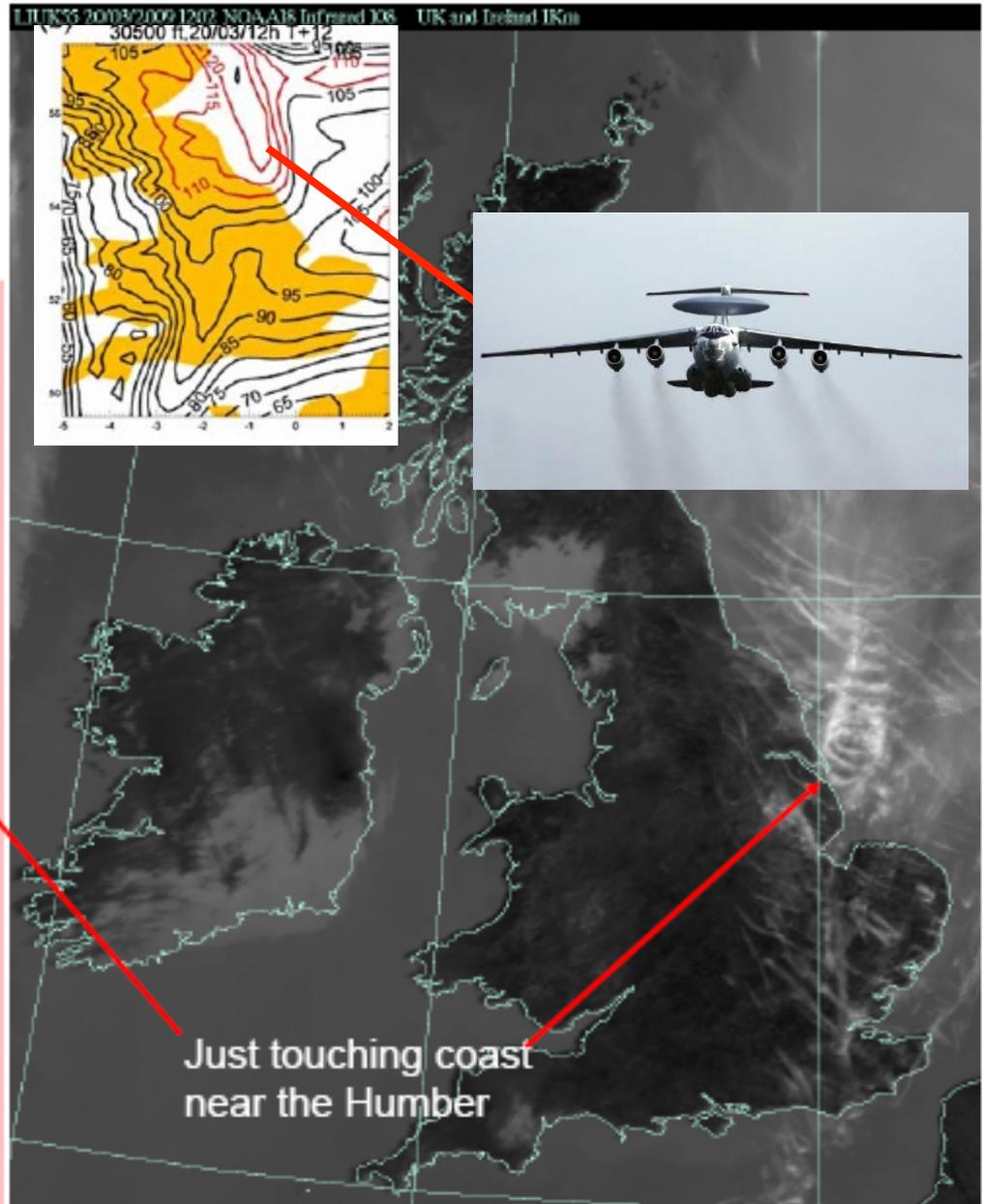
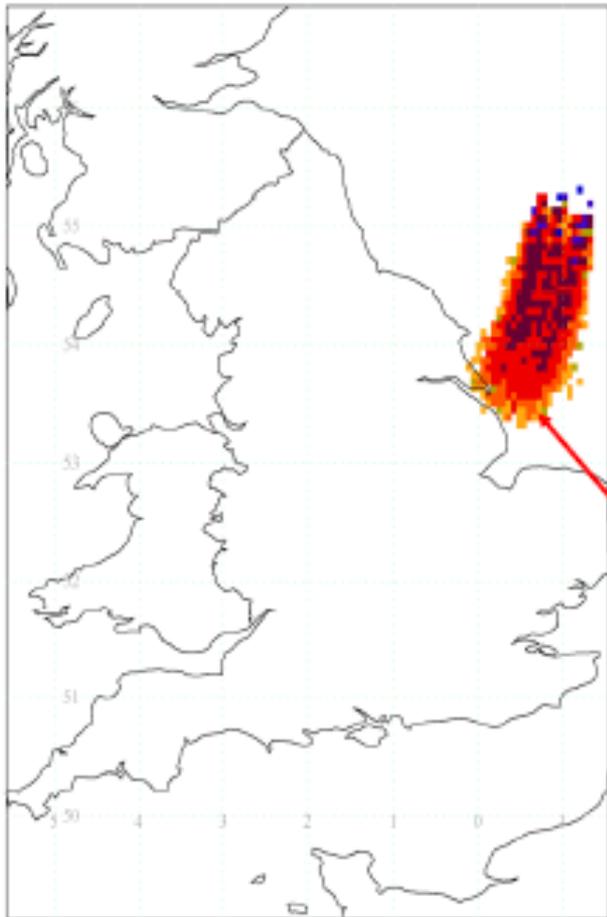
Albedo probability distribution over stratocumulus regions



- Positional errors/natural variability
- Amount/microphysical characteristics

Claire Barber PhD

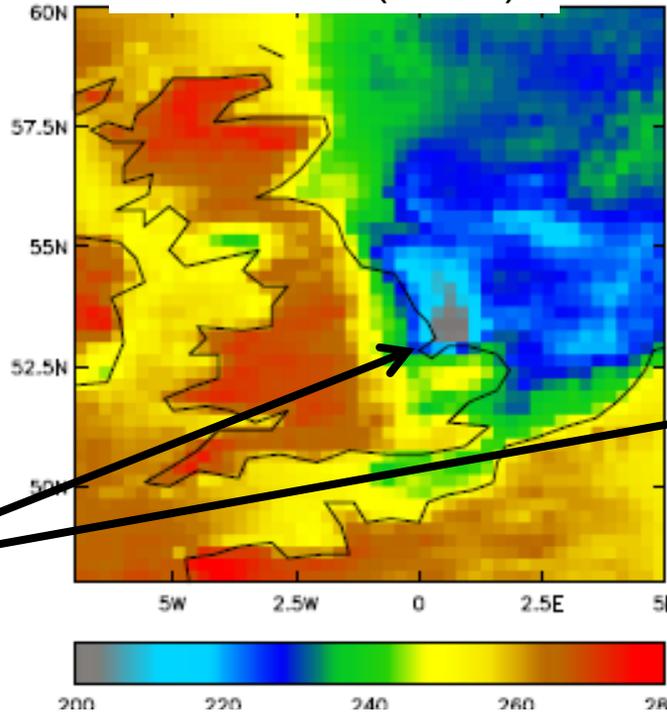
Radiative forcing: contrail cirrus



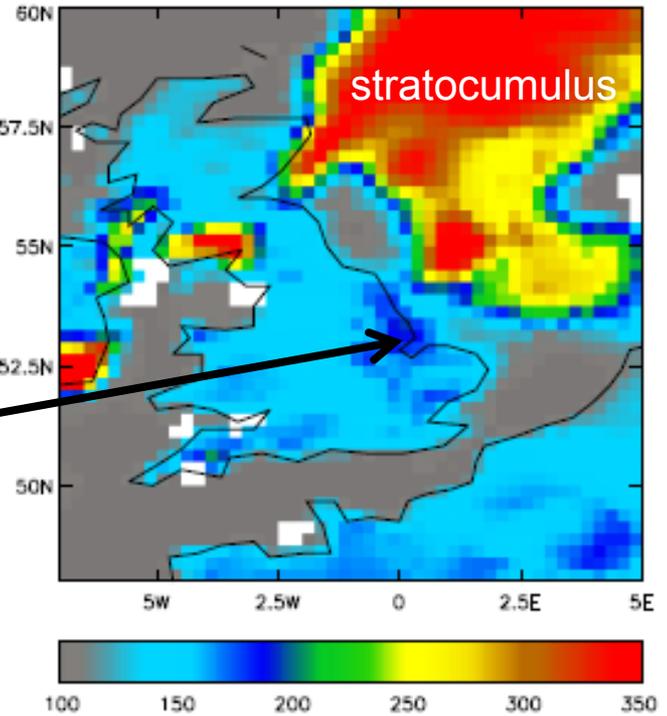
Courtesy of Jim Haywood

CERES FM3 (Aqua) fluxes 13:25

LW fluxes (Wm^{-2})



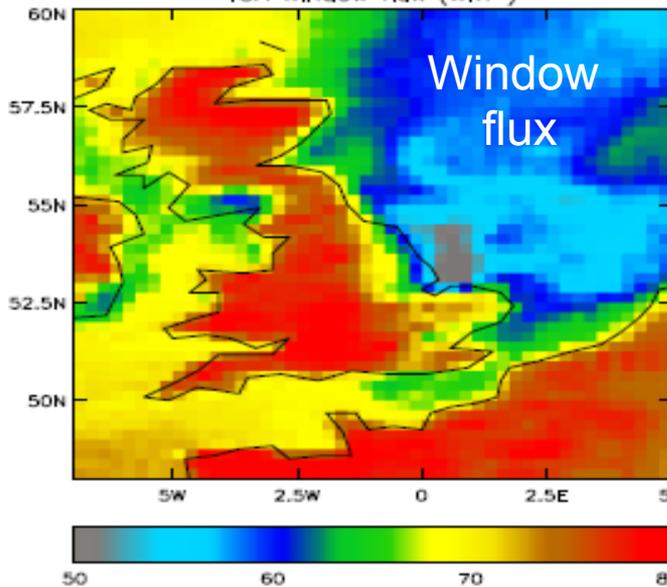
SW fluxes (Wm^{-2})



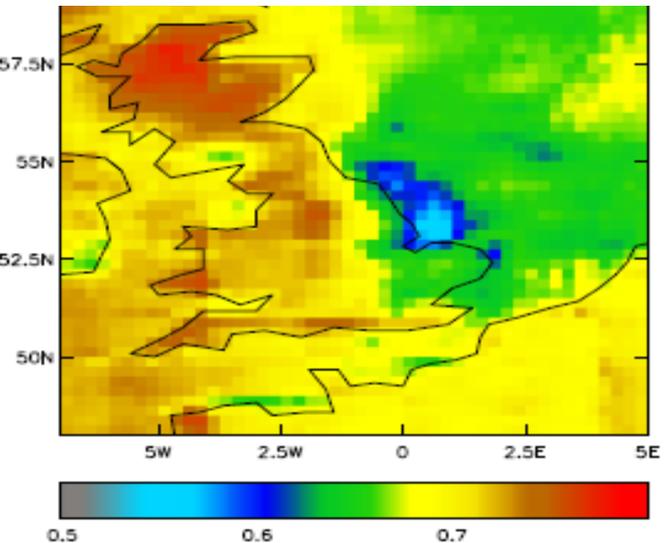
Contrail
induced
cirrus

Using GERB/
NWP model
estimate radiative
effect of contrail
cirrus:
LW $\sim 40 \text{ Wm}^{-2}$
SW up to 80 Wm^{-2}

TOA Window flux (Wm^{-2})



Inverse greenhouse parameter



Using GERB-like/SEVIRI to quantify contrail radiative effects

Example at 14:00Z

SEVIRI

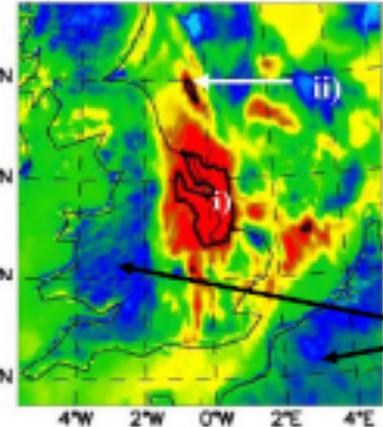
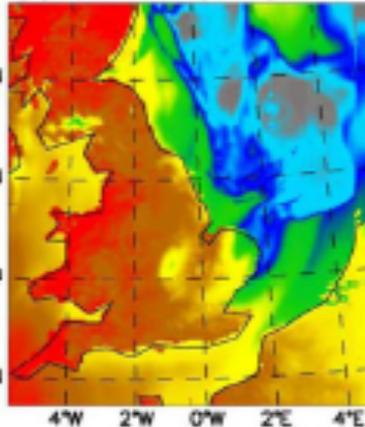
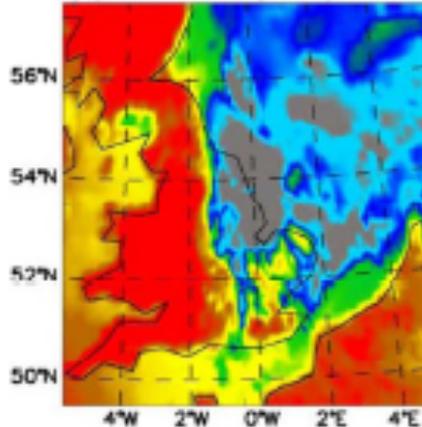
UK4

UK4-SEVIRI:
Radiative forcing

(a) SEVIRI LW (Wm^{-2}) 14:00

(b) Model LW (Wm^{-2}) 14:00

(c) Model-SEVIRI LW (Wm^{-2})



i) & ii)
Areas $>$
 40Wm^{-2}

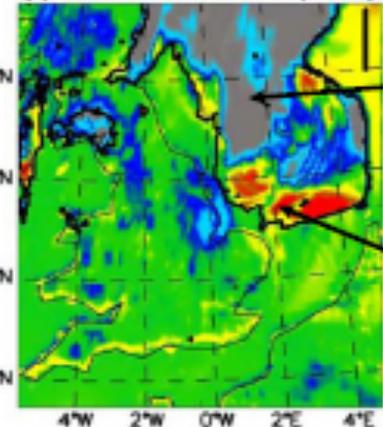
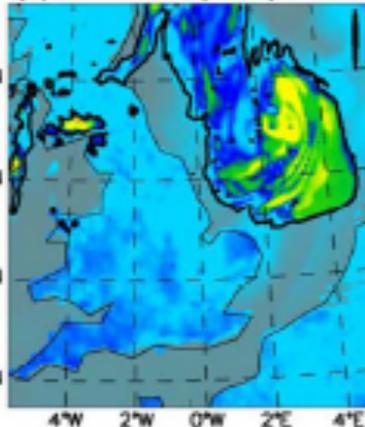
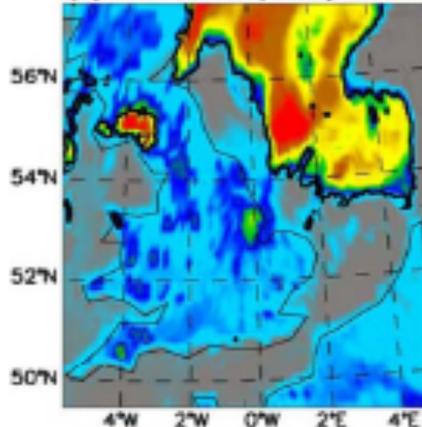
Cold bias over
land in UK4
model in
cloud free
regions (*John
Edwards, pers
comm*)

LW
(no cloud
screening)

(d) SEVIRI SW (Wm^{-2}) 14:00

(e) Model SW (Wm^{-2}) 14:00

(f) Model-SEVIRI SW (Wm^{-2})



Very large
differences
in brightness
of Sc.
Some
positional
errors of the
model Sc

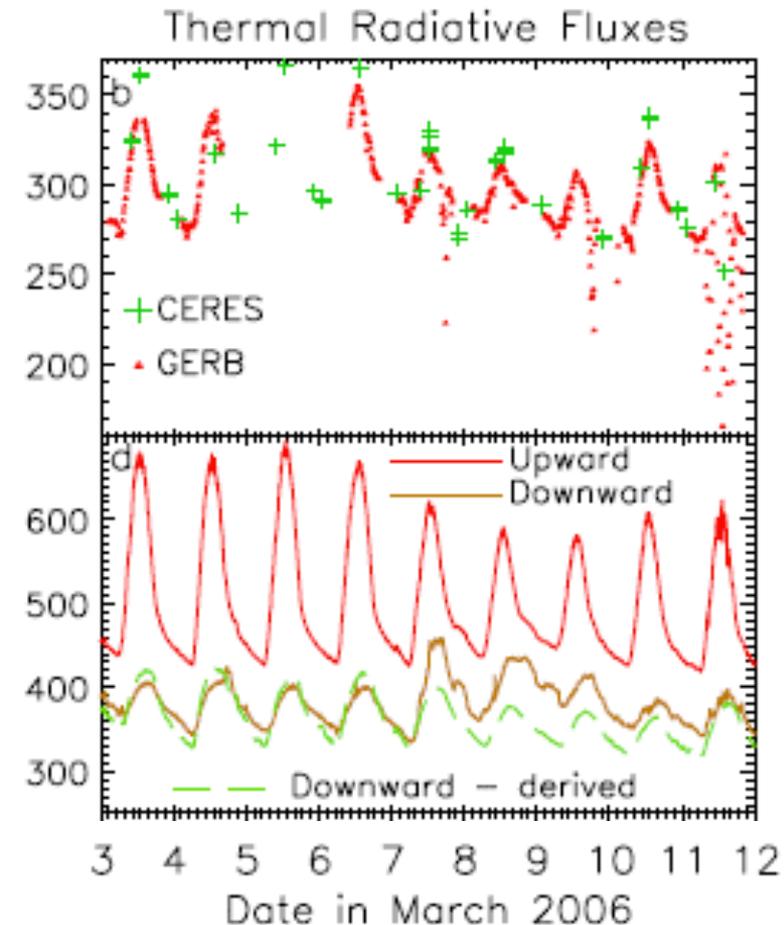
SW
(cloud mask
shown)

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Combining satellite and surface data: RADAGAST

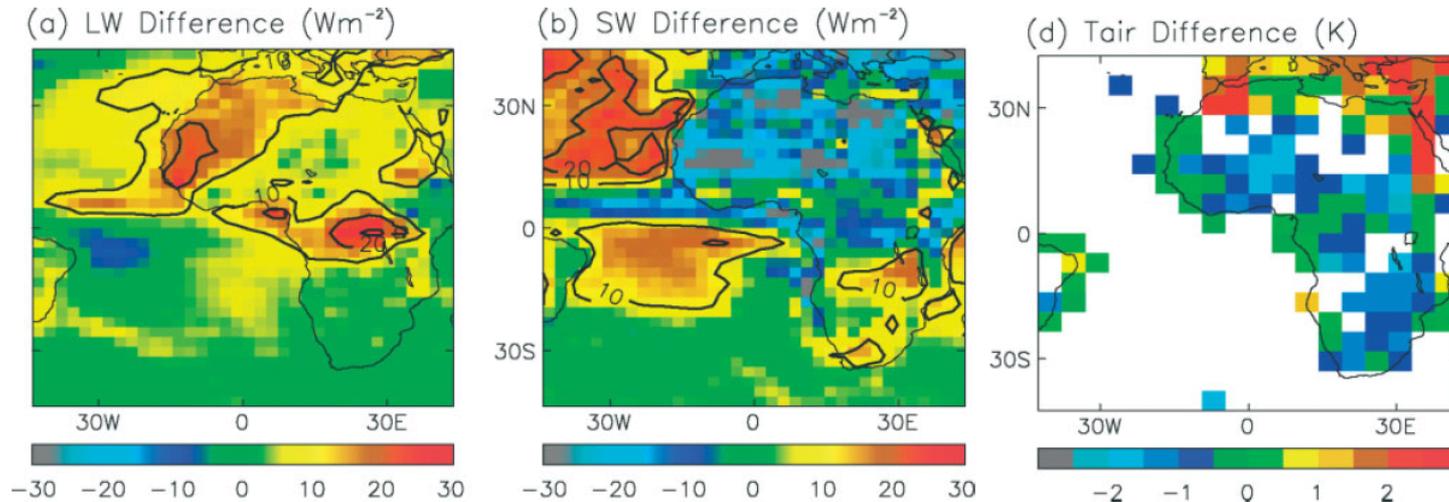


- Combining GERB/CERES and ARM
- Example: substantial radiative effect of mineral dust aerosol →
- Model LW biases up to 40 Wm^{-2}
- e.g. Haywood et al. (2005); Zhang and Christopher (2003)

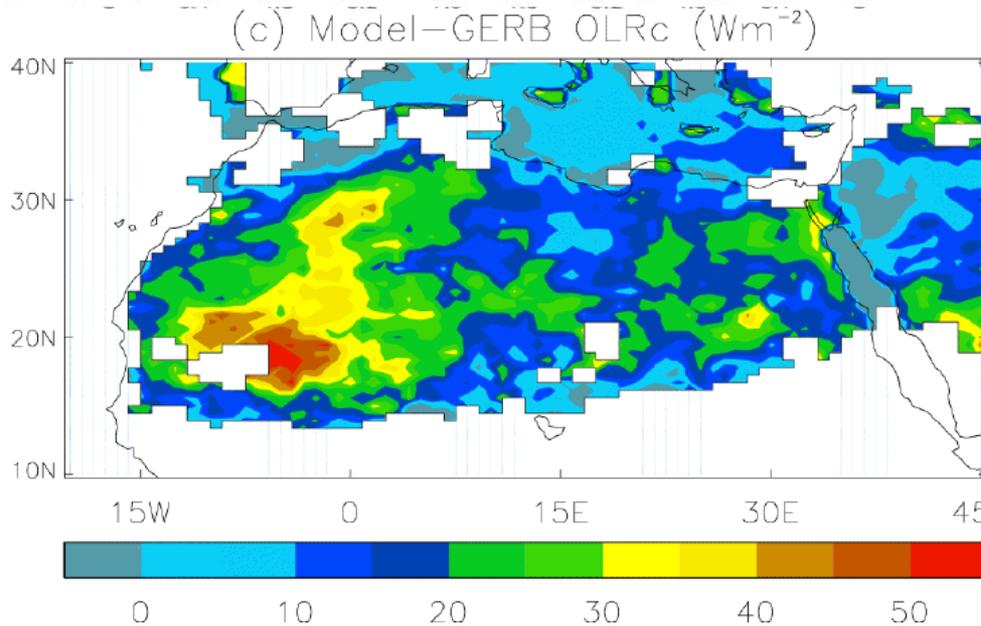


[Slingo et al. \(2006\) GRL](#)

Evaluating Systematic Model Errors in north Africa



Systematic biases in climate model radiation (models-CERES) and temperature

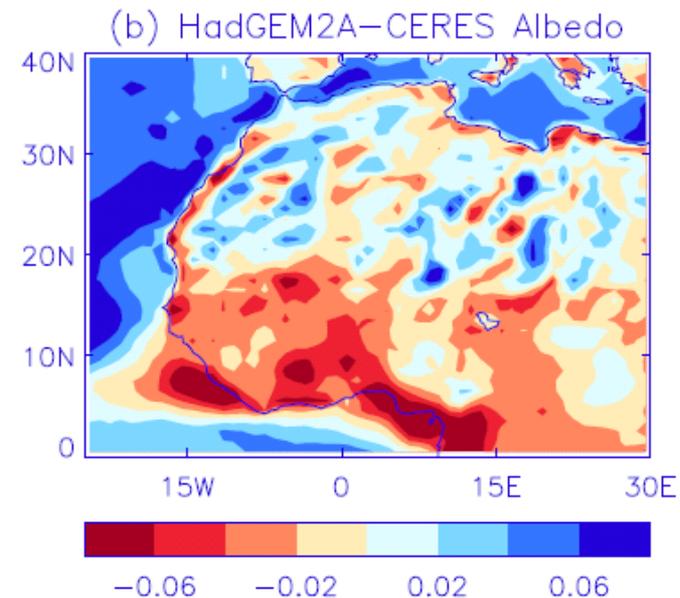
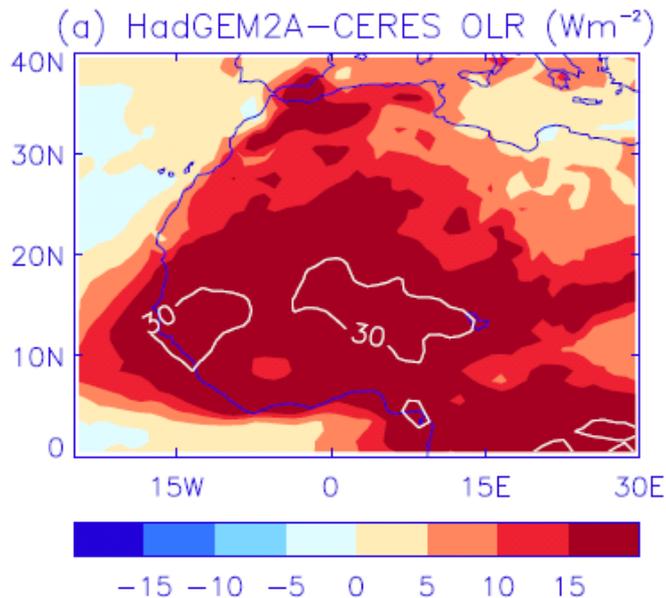
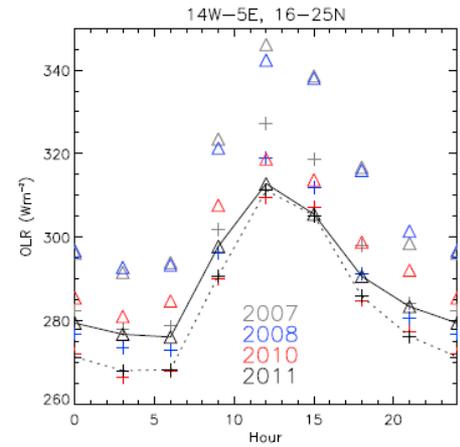
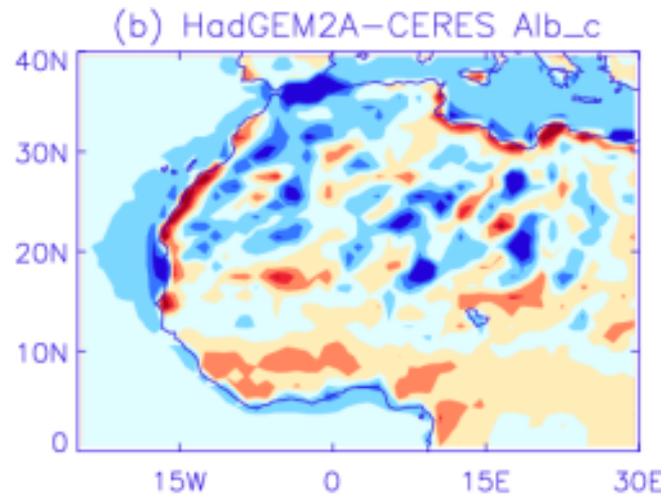
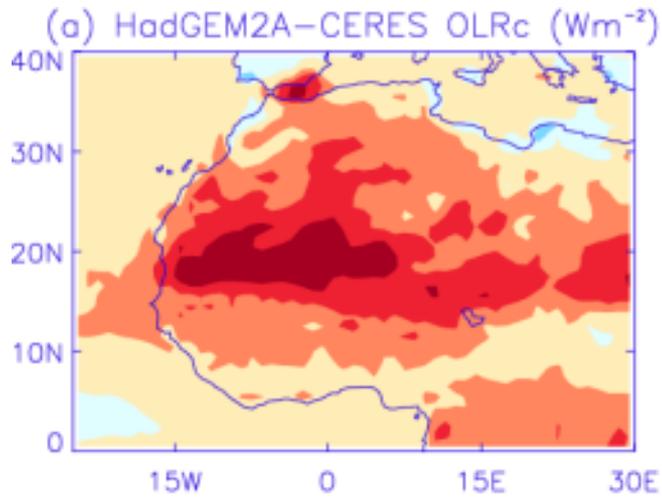


Longwave radiation over-estimated over Saharan Heat Low (model-GERB)

[Haywood et al, 2005 JGR](#)

[Allan et al. 2011, QJRM](#)

HadGEM2 biases vs CERES



DACCIWA - Dynamics-aerosol-chemistry- cloud interactions in West Africa

EU consortium lead by Peter Knipperts

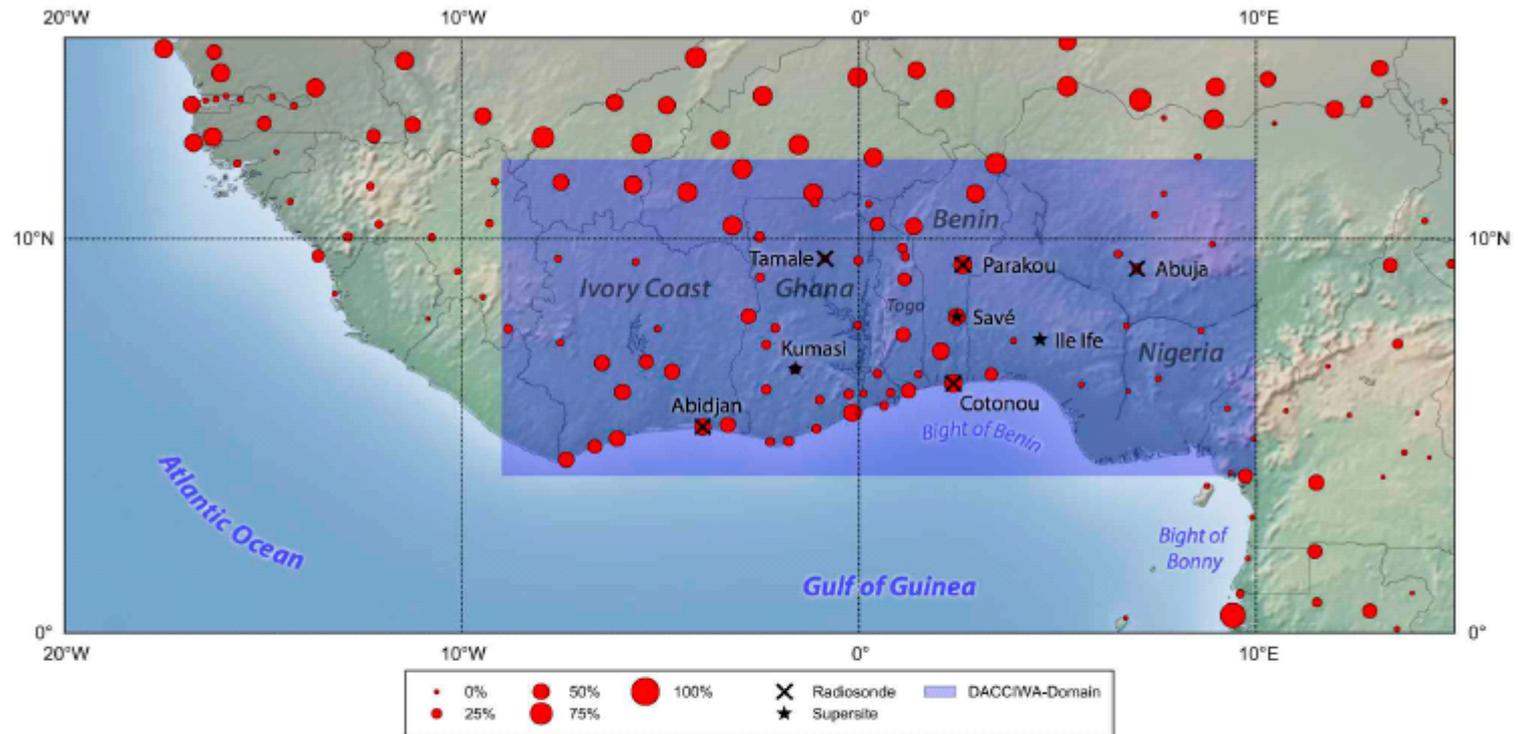
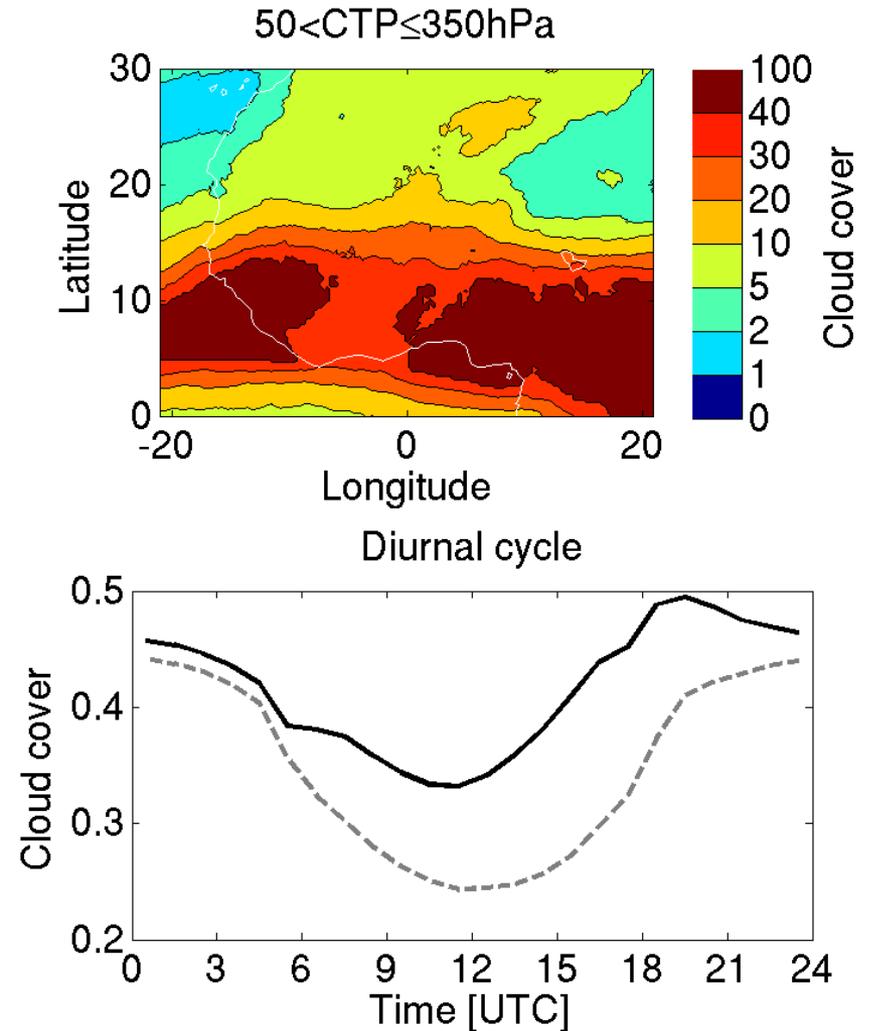
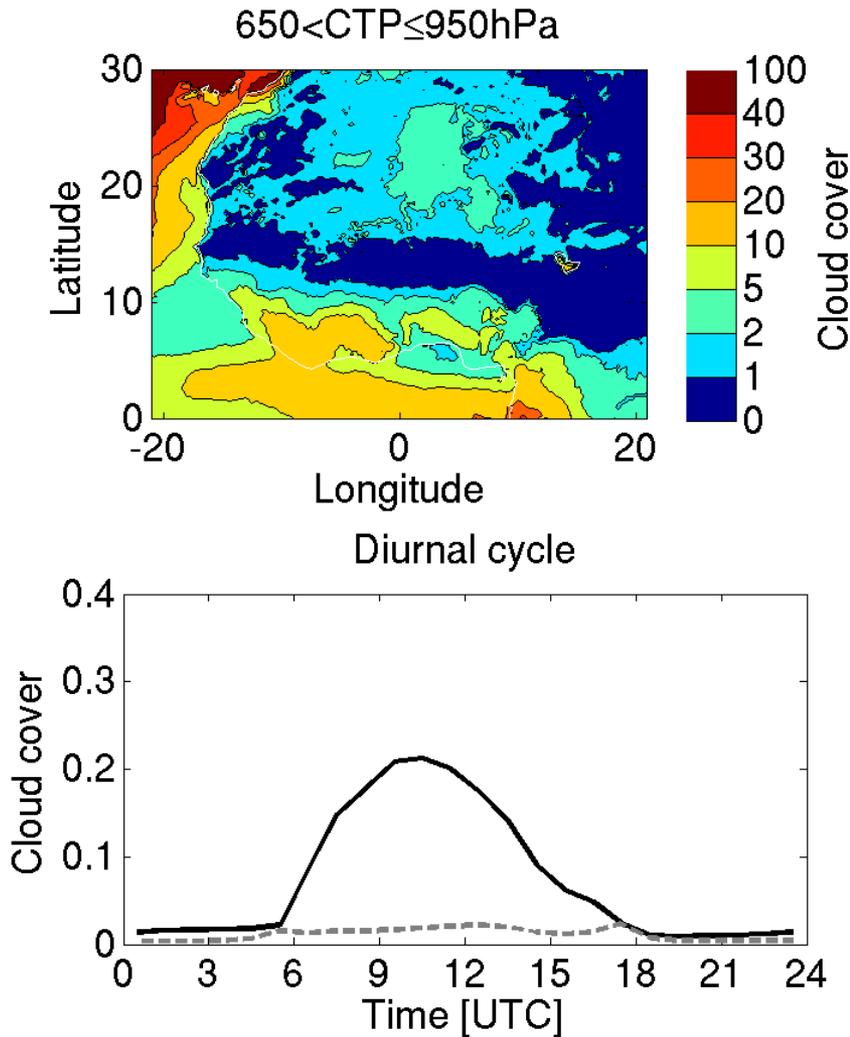
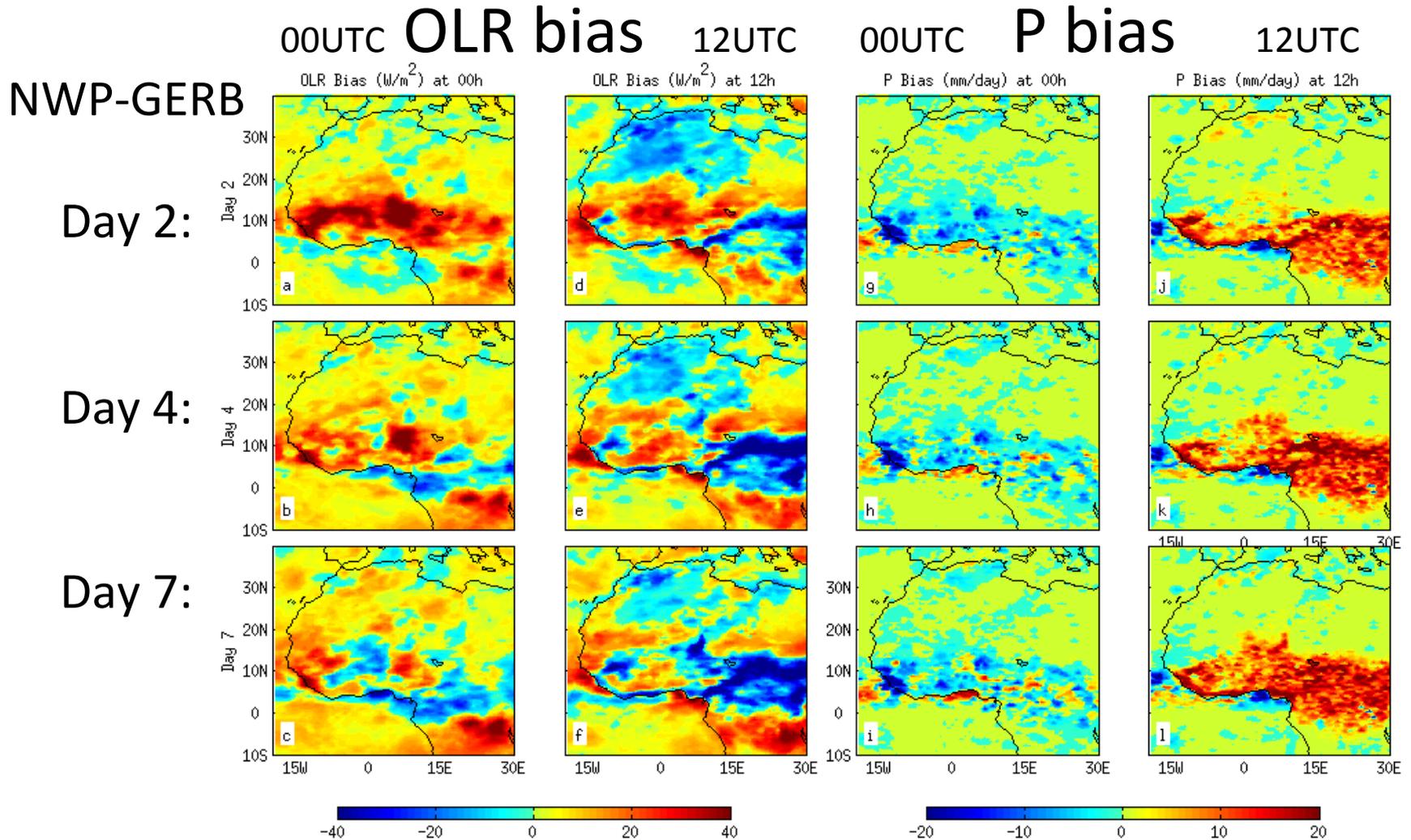


Figure 1.4: Geographical overview of the DACCIWA study area highlighted in blue. Supersites and planned radiosonde stations (black markers) and synoptic weather stations (red dots, proportional to available number of reports in the WMO Global Telecommunication System from 1998–2012).

DACCIWA preliminary analysis of cloud cover

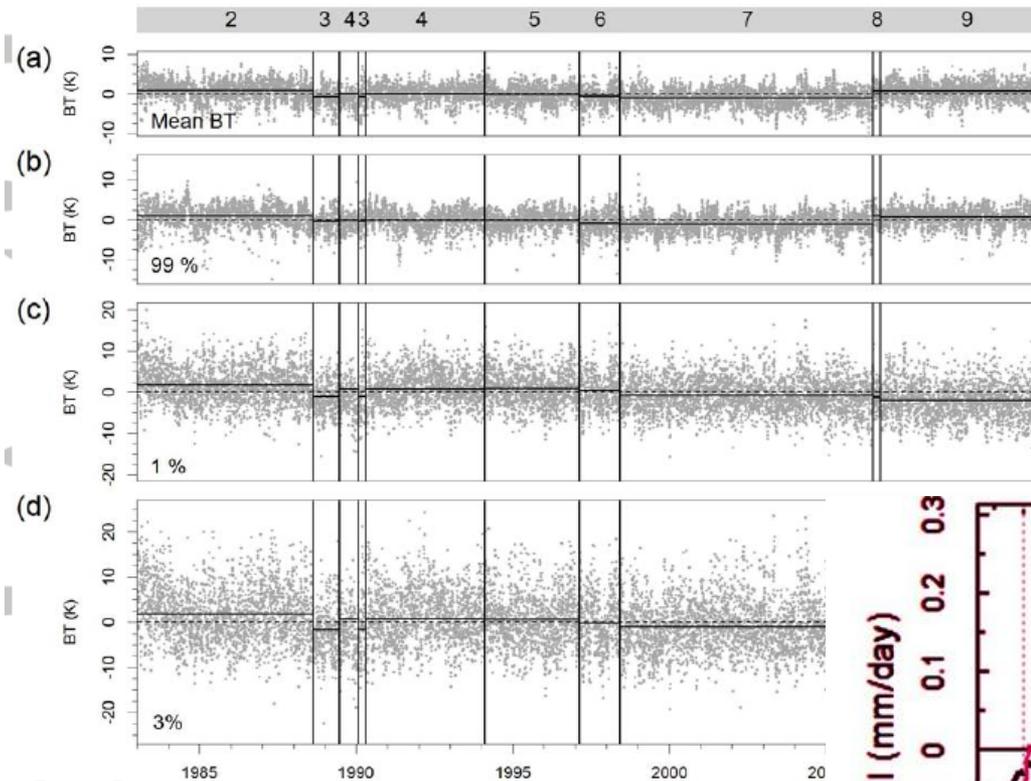


Emerging Weather Forecast Model Biases in Radiation and Precipitation



See also [Liu et al. \(2014\) JAMC](#)

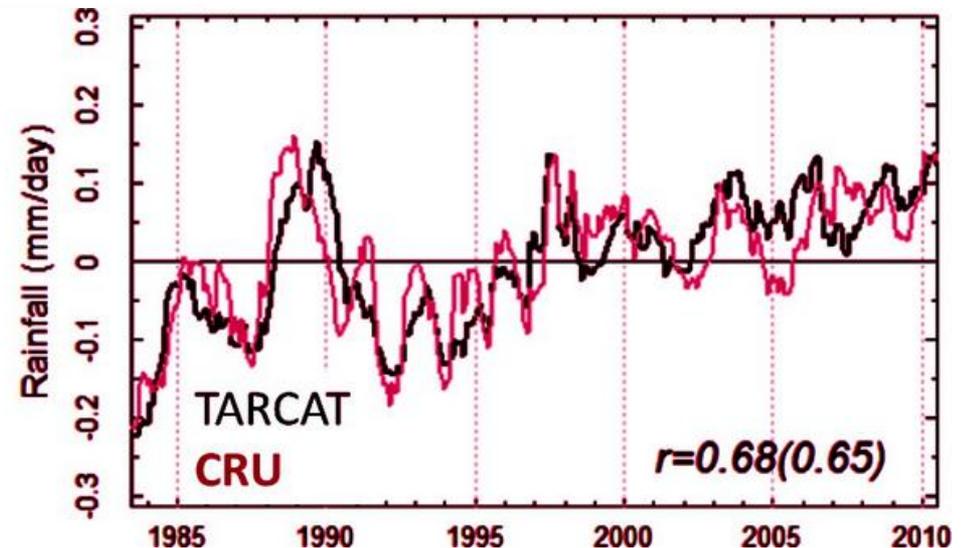
Homogeneous Africa rainfall record from Meteosat



- 30yr Meteosat window channel BT record
- CCD rainfall proxy

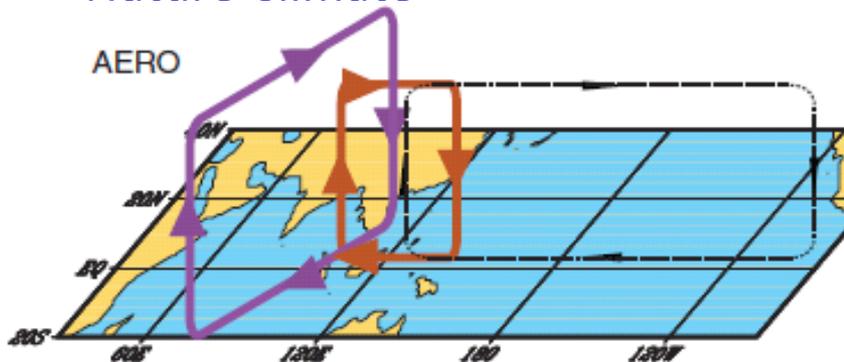
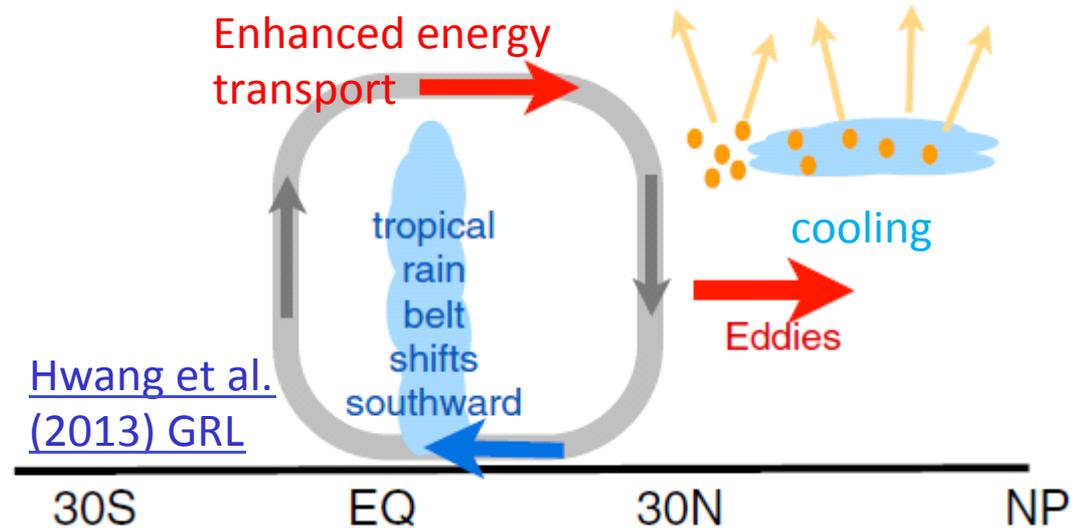
[Maidment et al. \(2014\) JGR](#)

Rain-gauge (CRU) variability captured by TAMSAT →



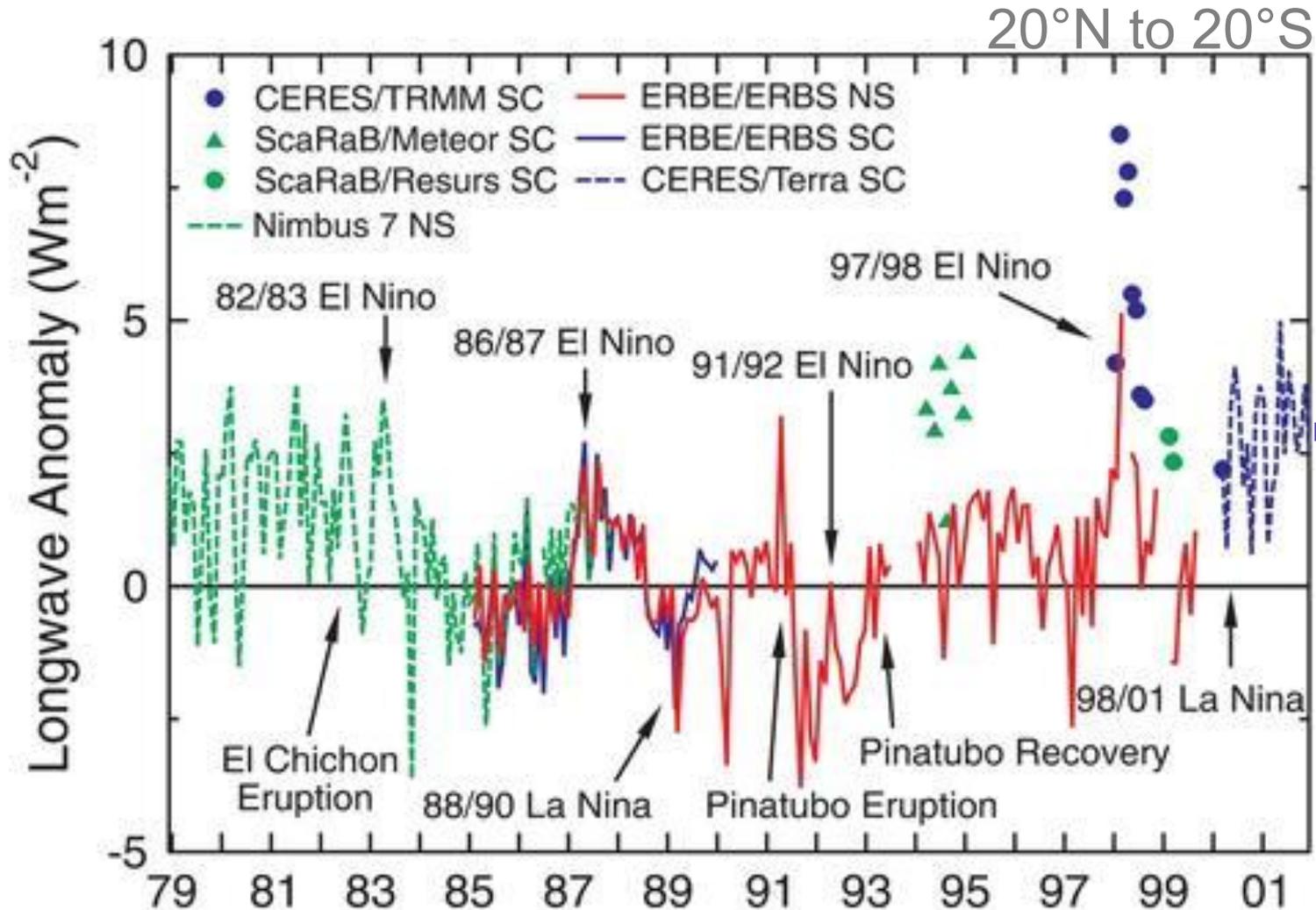
Interhemispheric heating and the water cycle

- N Hemisphere Aerosol cooling 1950-1980s
- Induces southward movement of ITCZ
- Reduced **Sahel rainfall** →
- Recovery after 1980s e.g. [Wild 2012 BAMS](#)
- +Asymmetric volcanic forcing e.g. [Haywood et al. \(2013\) Nature Climate](#)



- Sulphate aerosol effects on Asian monsoon e.g. [Bollasina et al. 2011 Science](#) (left)
- Links to drought in Horn of Africa? [Park et al. \(2011\) Clim Dyn](#)
- Recovery in Sahel rainfall e.g. [Maidment et al. \(2014\) JGR](#)

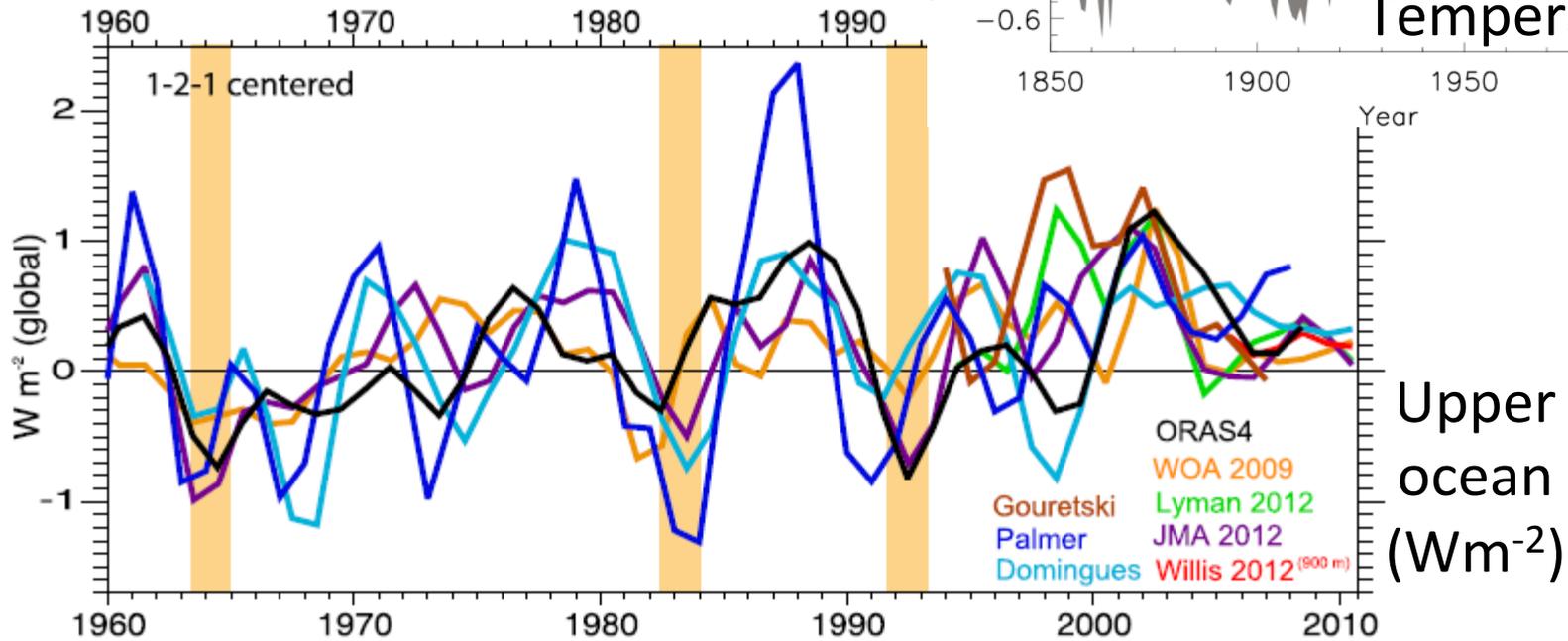
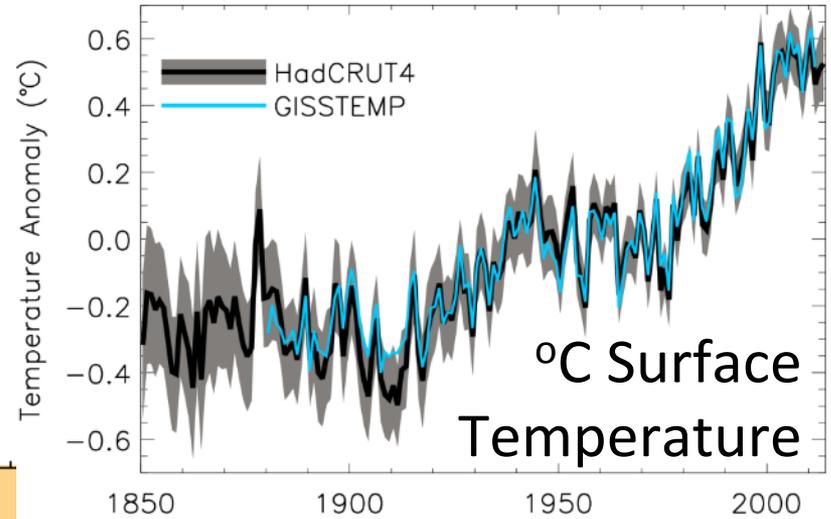
Changes in Earth's radiative energy balance



[Wong et al. \(2006\) J Clim](#); [Wielicki et al. \(2002\) Science](#)

At what rate is Earth heating?

Global Annual Mean Temperature Anomaly

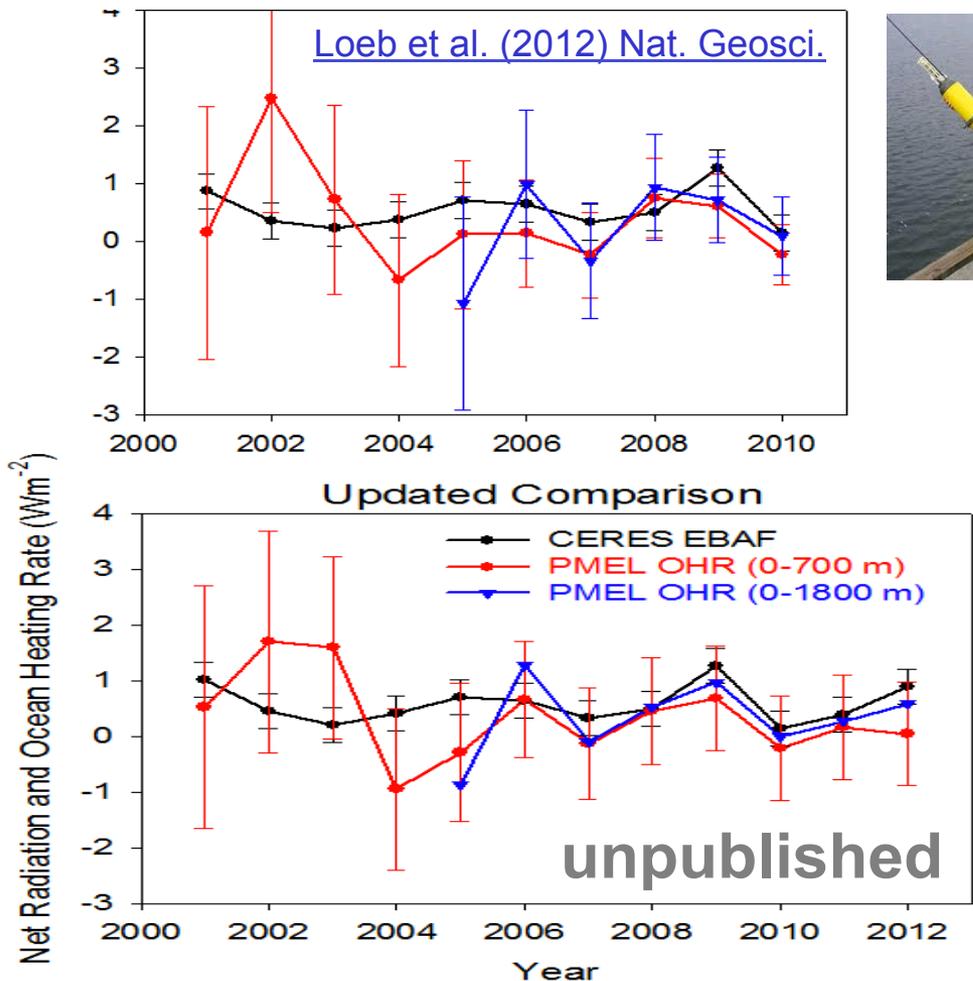


[Trenberth et al. \(2014\) J Clim](#)

Combining Earth Radiation Budget data and Ocean Heat Content measurements



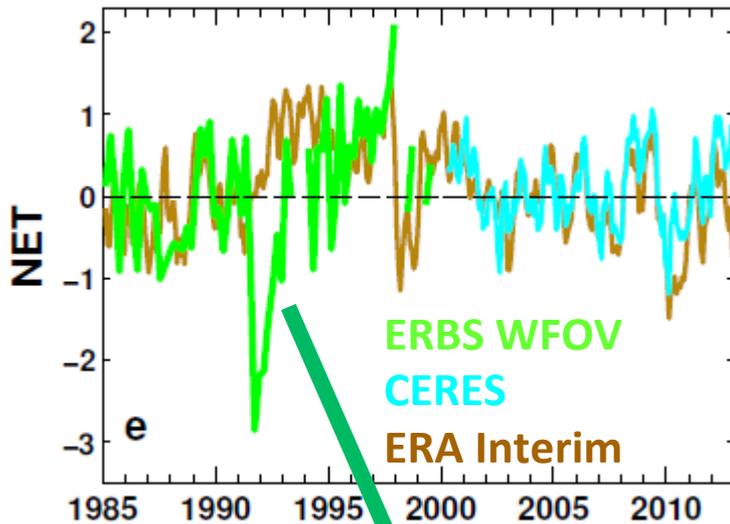
- Tie 10-year CERES record with SORCE TSI and ARGO-estimated heating rate 2005-2010 + minor additional storage terms
- Variability relating to ENSO reproduced by CERES and ERA Interim
- Ocean heating rate sensitive to dataset and sampling
- What about prior to 2000?



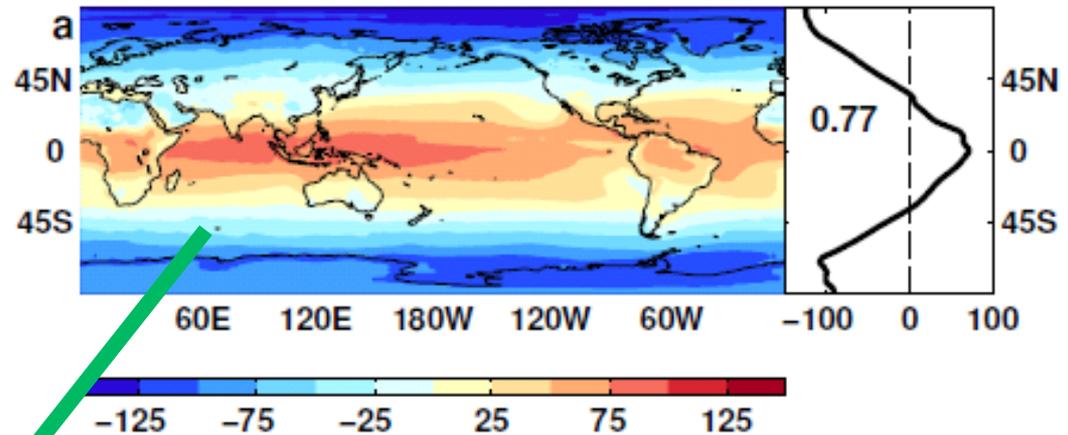
[Loeb et al. \(2012\) Nat. Geosci.](#) See also [Hansen et al. \(2011\) ACP](#)

Reconstructing global radiative fluxes prior to 2000

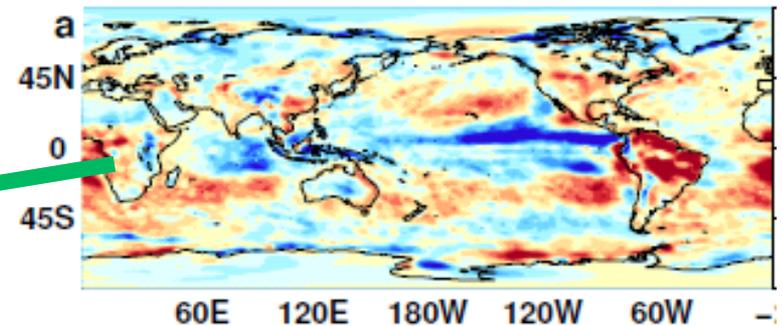
ERBS/CERES variability



CERES monthly climatology



ERA Interim spatial anomalies

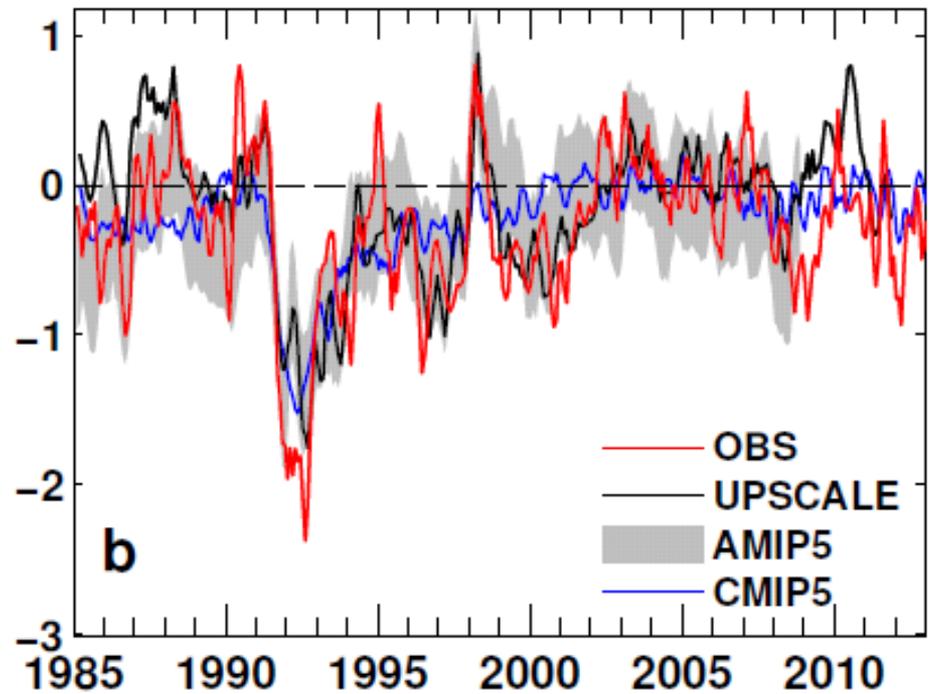


Combine CERES/ARGO accuracy,
ERBS WFOV stability and
reanalysis circulation patterns to
reconstruct radiative fluxes

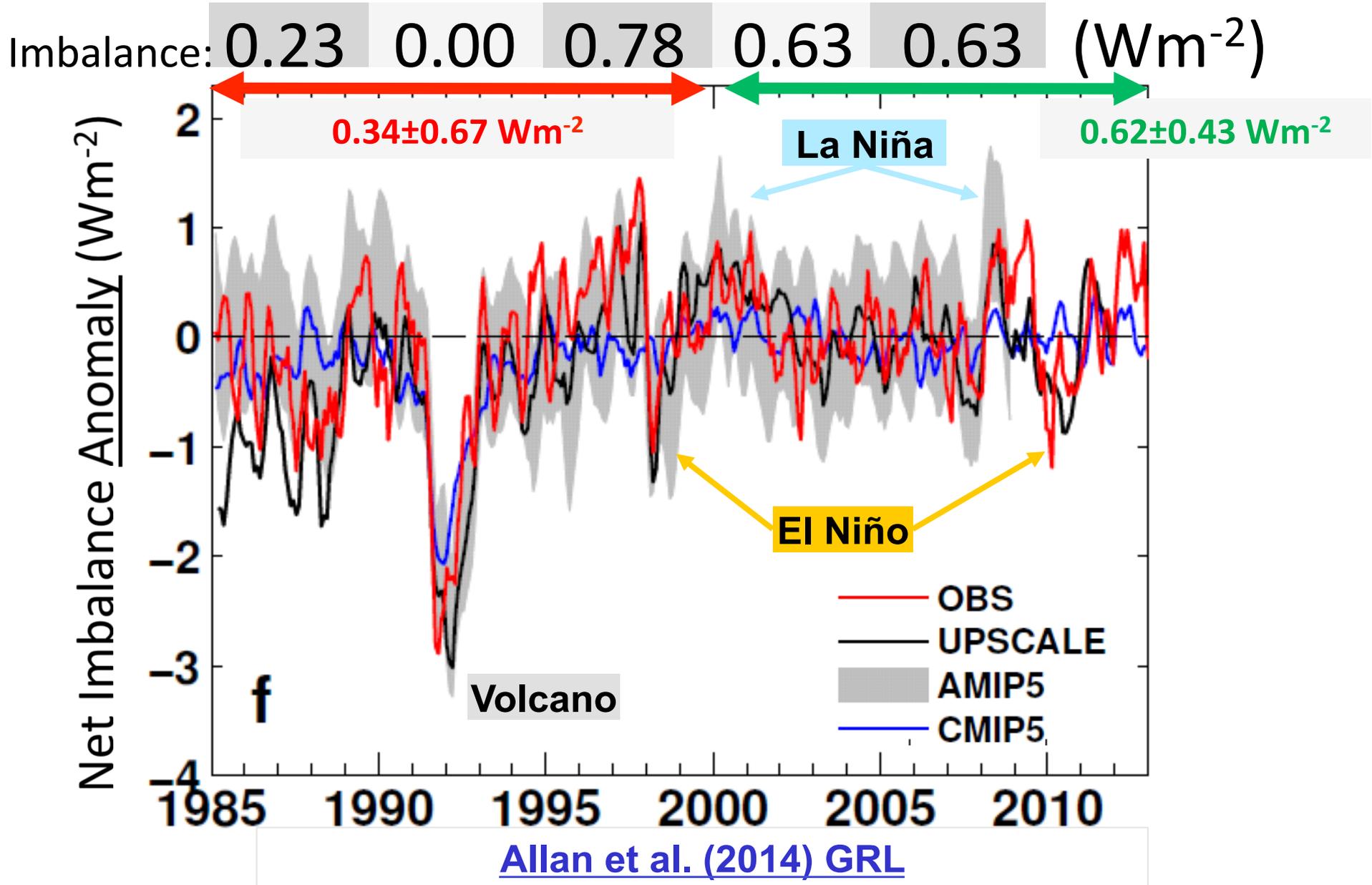
Use reanalyses or models to bridge gaps in record (1993 and 1999/2000)

- ERA Interim trends suspect. Use model...
- **UPSCALE** simulations (obs. SST, sea ice & realistic radiative forcings) “**OBS**”
- Net less sensitive to method than OLR/ASR

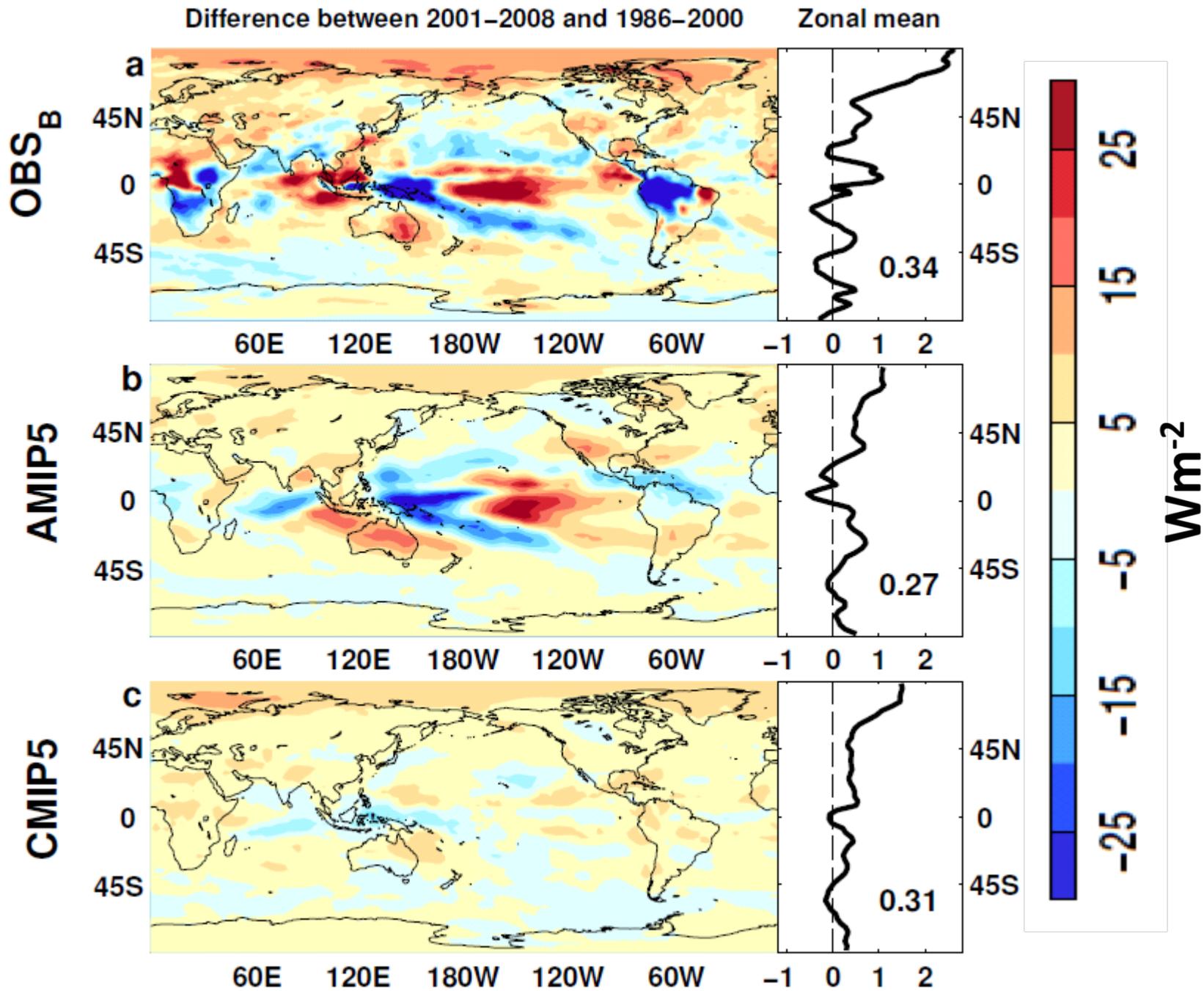
Outgoing Longwave Radiation Anomalies (Wm^{-2})



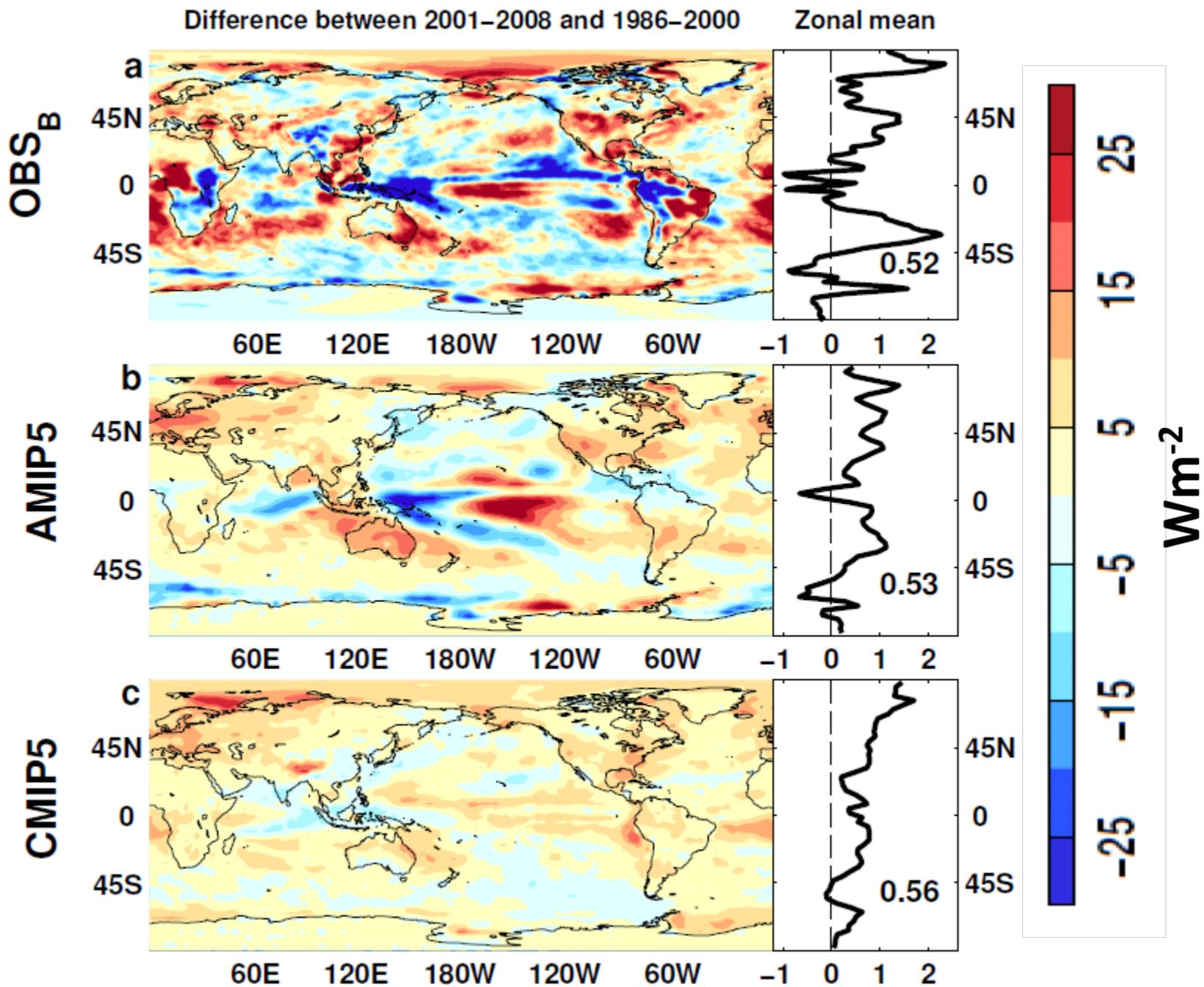
Changes in imbalance in models & observations



**Outgoing
Longwave
Radiation**



Absorbed Shortwave Radiation

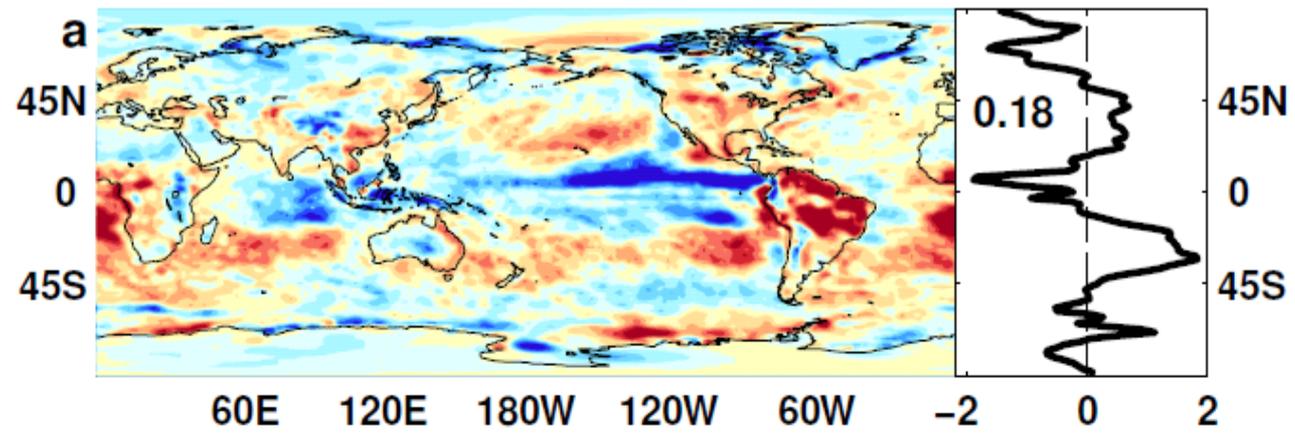


NET Radiation

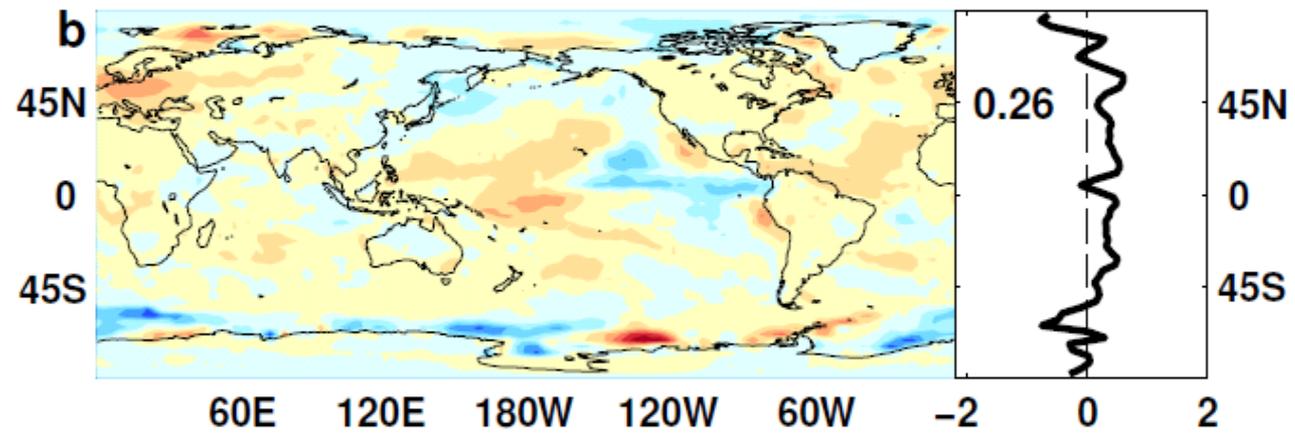
OBS_B

Difference between 2001–2008 and 1986–2000

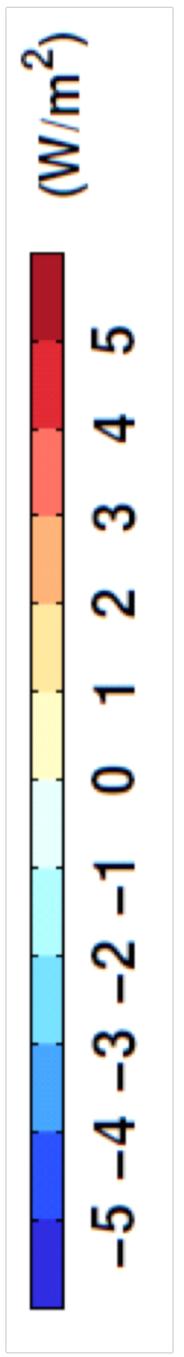
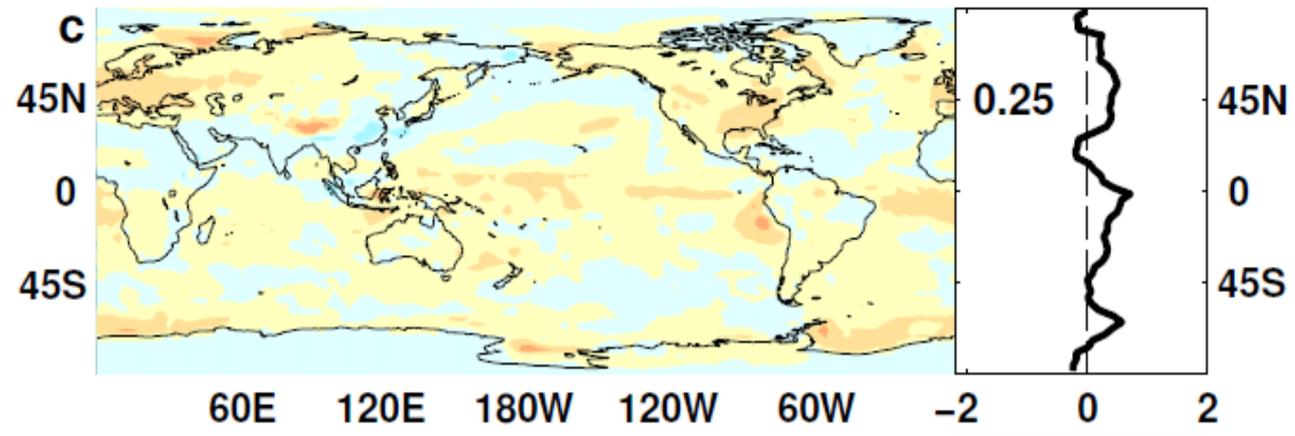
Zonal mean



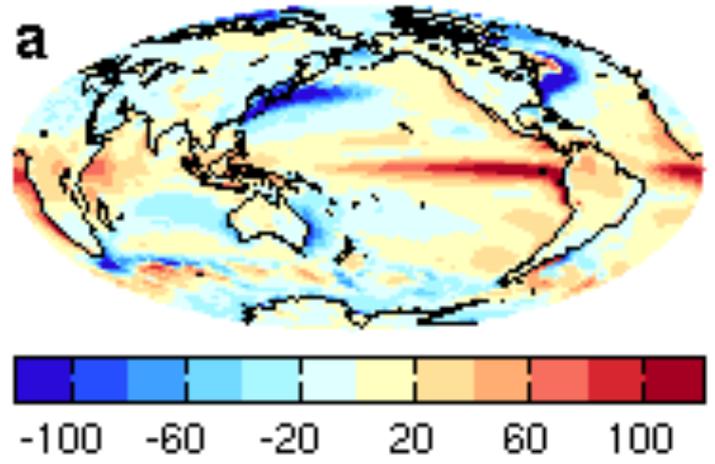
AMIP5



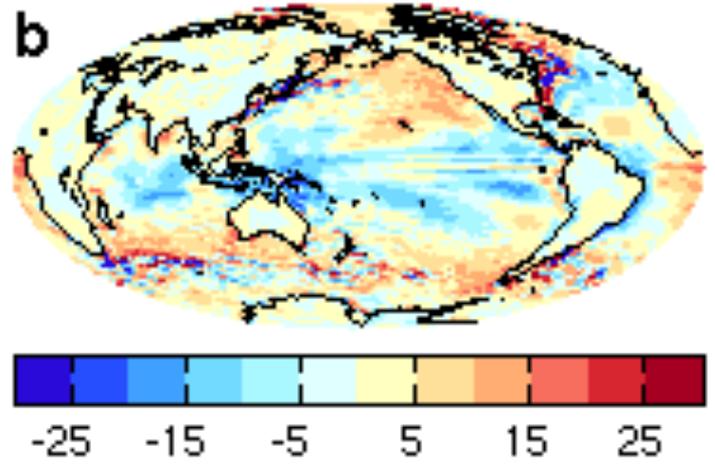
CMIP5



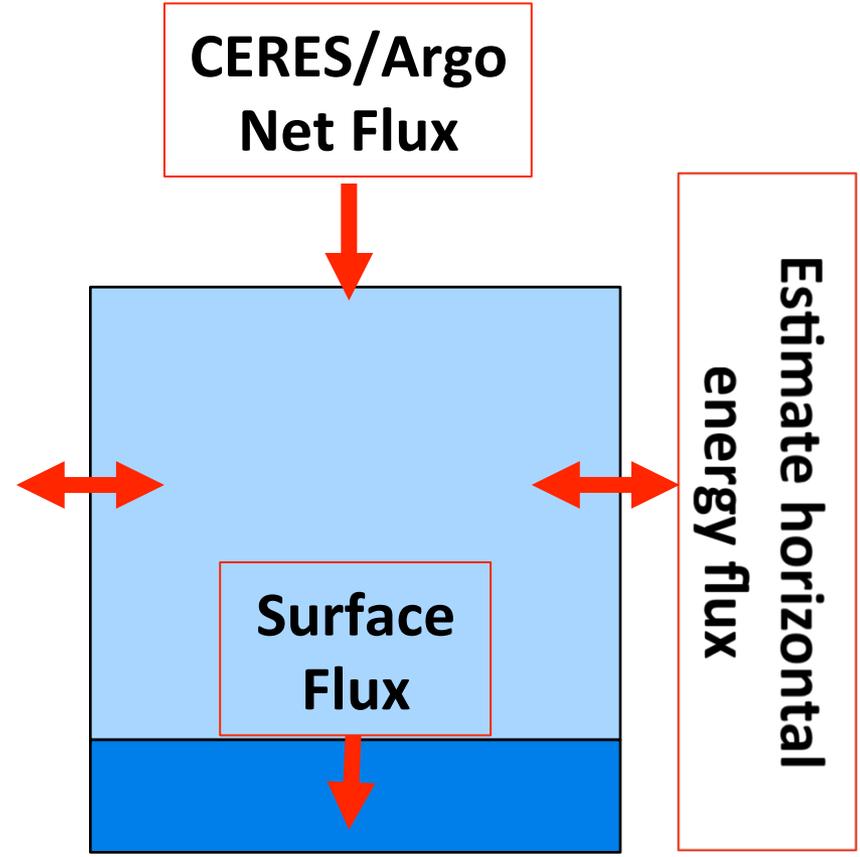
Net downward surface flux (W/m²)
2001-2005



Difference (W/m²)
(2001-2008 - 1986-2000)



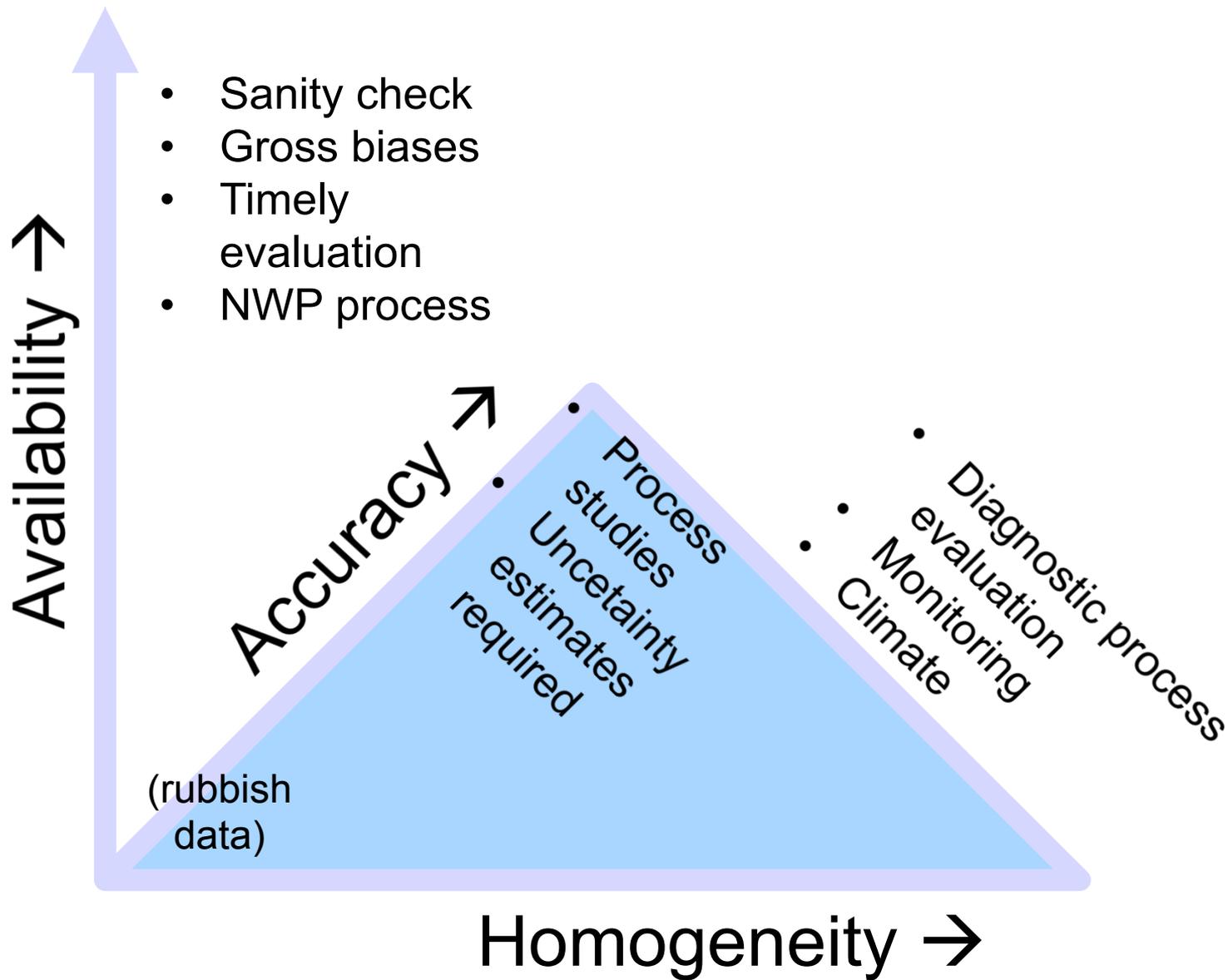
Next steps: estimates of Surface Flux



$$F_{\downarrow SFC} = F_{\downarrow TOA} - \frac{\partial TE}{\partial t} - \nabla \cdot \mathbf{1}/g \int_0^{\pi} \mathbf{1} \cdot V (Lq + C_p T + \phi s + k) \partial p / \partial \eta d\eta$$

Conclusions

- Synergy between different ERB and other sensors
 - Essential in understanding processes
 - Confirming biases in models... or data
- Different challenges, different problems...
 - Bottom up: evaluation at model time-step required in understanding & improving process representation
 - Top down: diagnosing and understanding climate change
- Net radiative flux imbalance fairly stable $\sim 0.6 \text{ Wm}^{-2}$
 - Requires anchoring to ARGO ocean heating rate + minor terms
 - Influence of Pinatubo and ENSO
 - Radiative forcing alone can't explain surface warming slowdown: internal variability important
 - Reliability of CERES/GERB decadal trends?



Conclusions

- Heating of Earth continues at rate of $\sim 0.6 \text{ Wm}^{-2}$
 - Variability from radiative forcings & ocean changes
- Radiative transfer & Thermodynamics explain increased global precipitation with warming $\approx 2\%/K$
 - Radiative forcings also affect water cycle responses
 - Greenhouse gas & absorbing aerosol forcing suppress global precipitation response to warming
- Inter-hemispheric heating, moisture budget & unforced variability dictate regional responses
- How has the “hiatus” affected water cycle?
- How do changes in cloud/circulation fit in?
- Where is energy going? NERC [DEEP-C](#) project...

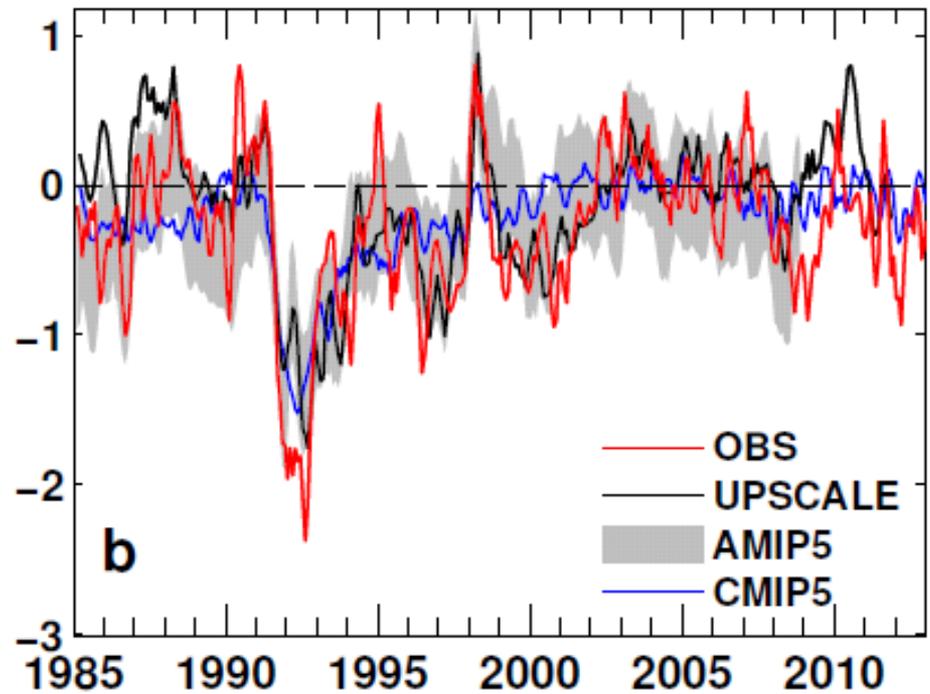
Combined CERES/Argo data

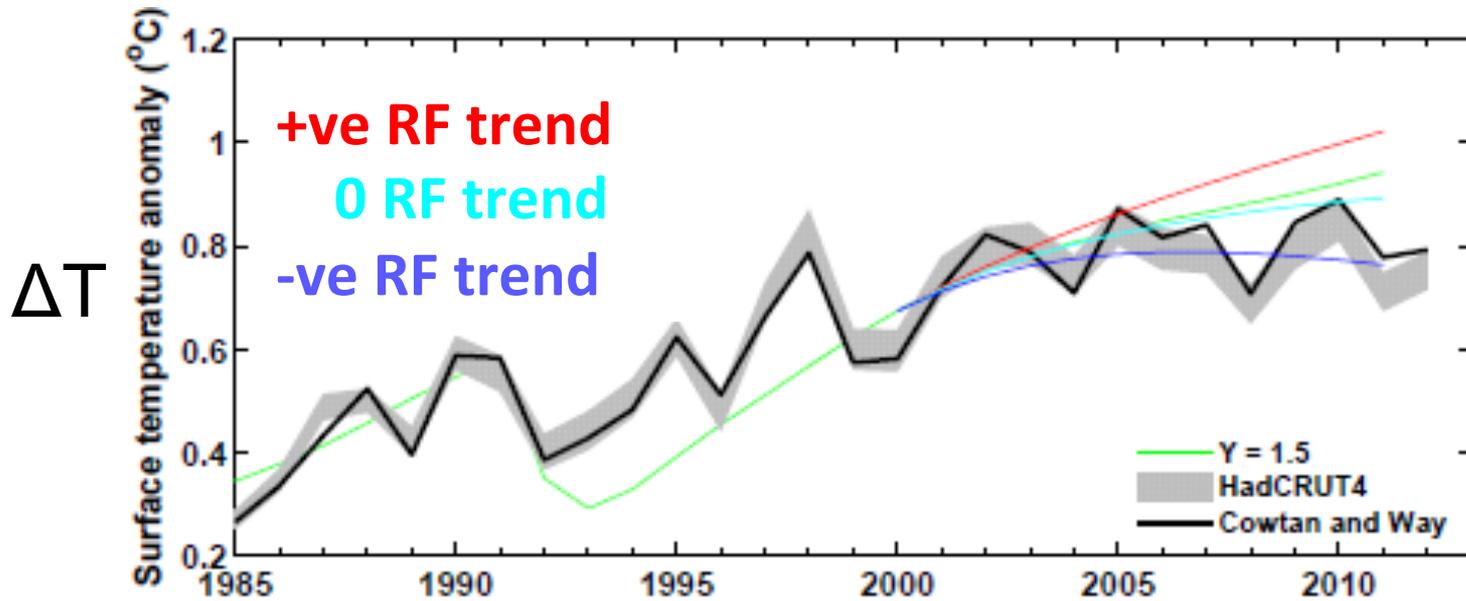
- Incoming Solar: SORCE Level 3 V10
- Reflected Shortwave/Outgoing Longwave from EBAF
 - (v2.6r → v2.8 → V3...)
- Added errors in quadrature to give $\pm 0.43 \text{ Wm}^{-2}$
 - Argo 0-2000m dOHCA/dt = $0.47 \pm 0.38 \text{ Wm}^{-2}$ (2005-2010)
 - >2000m $\sim 0.07 \pm 0.05 \text{ Wm}^{-2}$
 - Heating/melting ice, heating land/atmos $\sim 0.04 \pm 0.02 \text{ Wm}^{-2}$
 - CERES standard error $\pm 0.2 \text{ Wm}^{-2}$
- Jan 2001-Dec 2010: $0.50 \pm 0.43 \text{ Wm}^{-2}$ (EBAF V2.6r)
- March 2000 – February 2013: $0.60 \pm 0.43 \text{ Wm}^{-2}$ (EBAF V2.8)
- CERES scanner data: cloud mask → clear-sky fluxes; not possible for ERBS wide-field of view

Use reanalyses or models to bridge gaps in record (1993 and 1999/2000)

- ERA Interim trends suspect. Use model...
- **UPSCALE** simulations (obs. SST, sea ice & realistic radiative forcings) “**OBS**”
- Net less sensitive to method than OLR/ASR

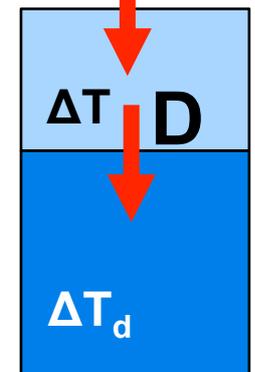
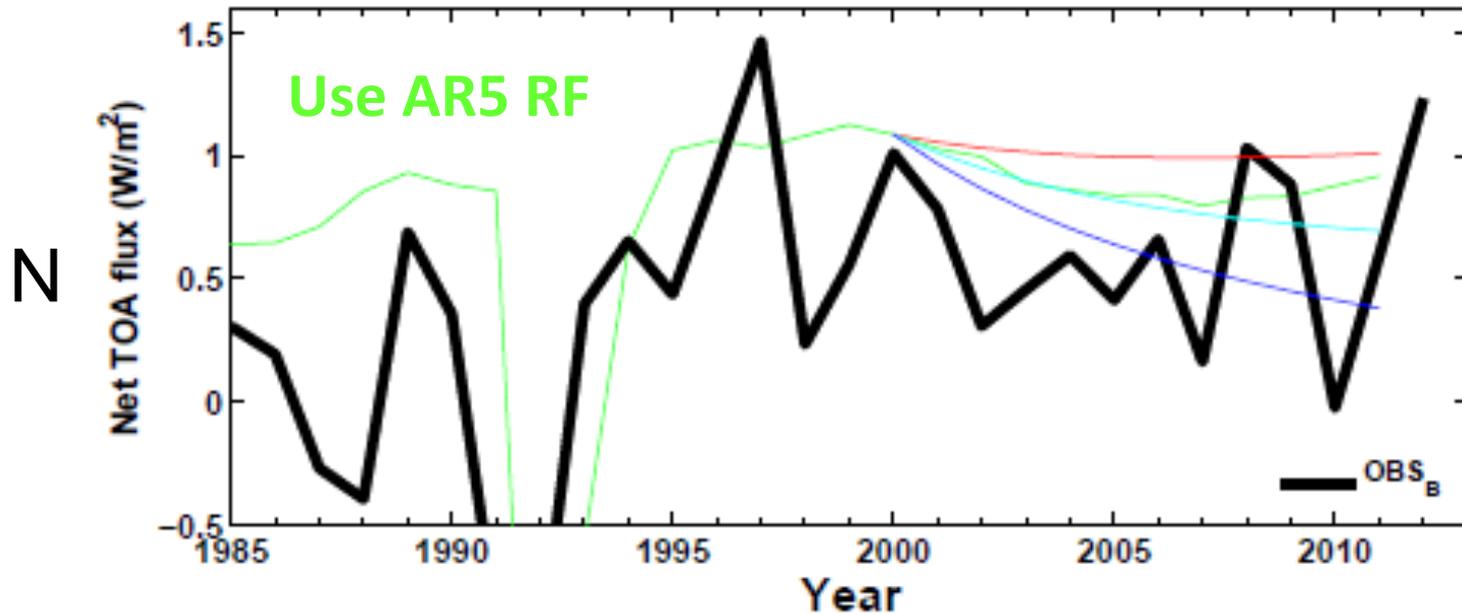
Outgoing Longwave Radiation Anomalies (Wm^{-2})





Analysis
 using
 simple
 energy
 balance
 model

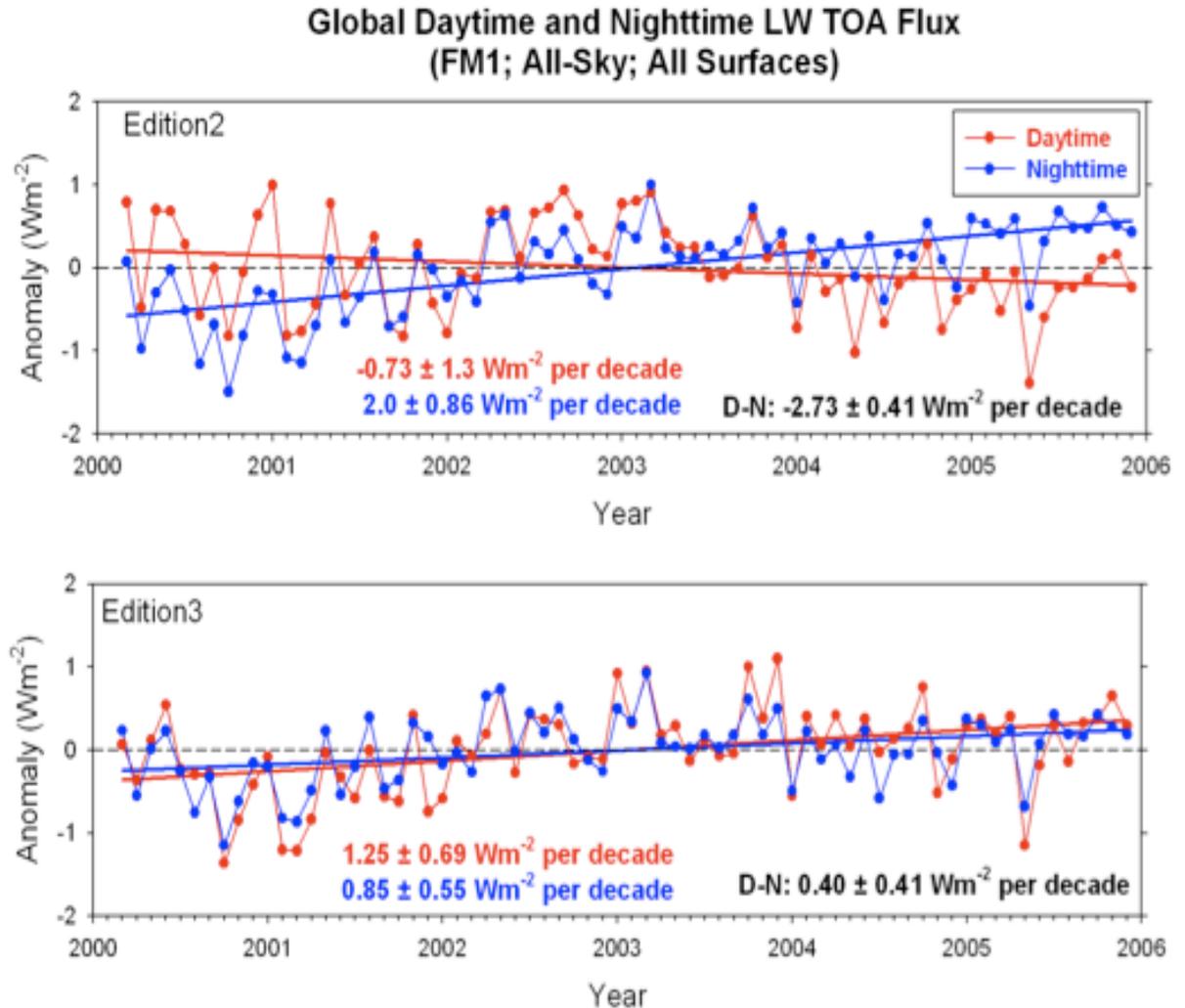
$$N = \Delta F - Y \Delta T$$





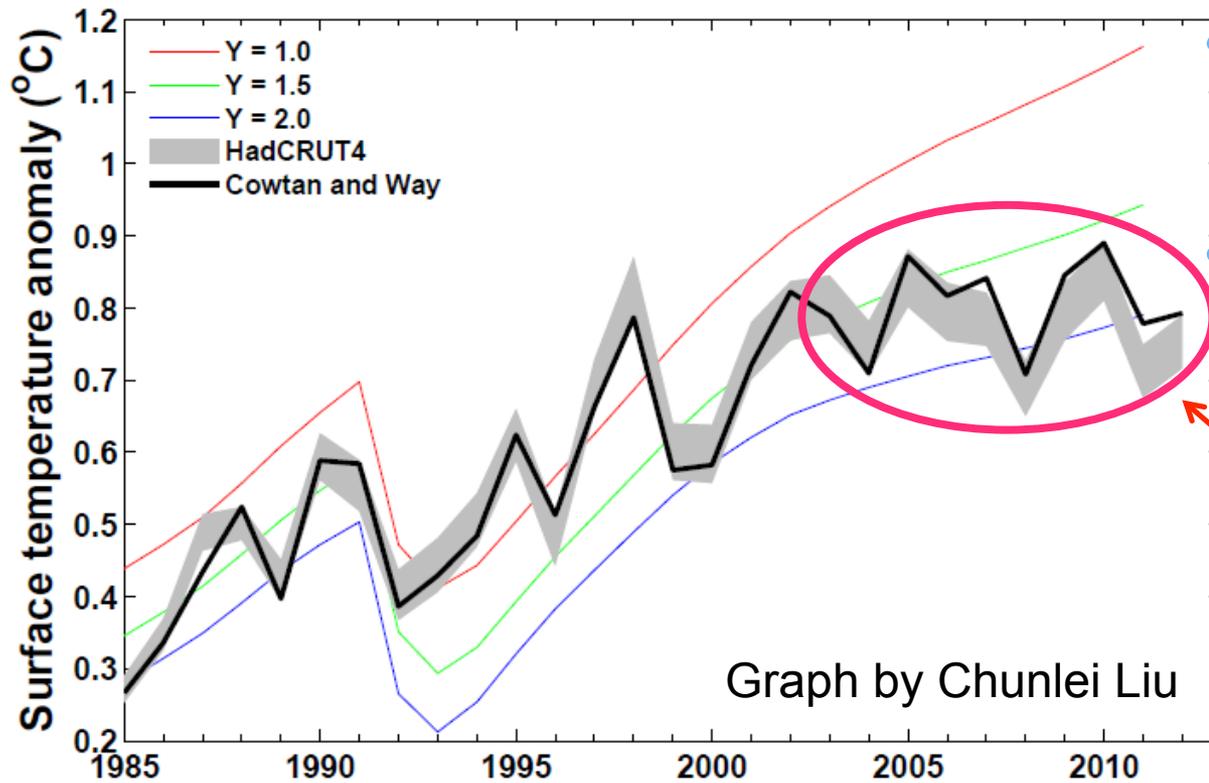
Updated CERES satellite data

- Issues with sampling, radiance to flux conversion, calibration, etc
- Correction for degradation of shortwave filter
- Correction also improves physical consistency of trends in daytime longwave



We used version CERES_EBAF-TOA_Ed2.6r; currently v2.8

Is the temperature record wrong or are computer models inaccurate?



Can comparisons tell us about how sensitive climate is to radiative forcing?
e.g.

[Otto et al. \(2013\)](#)

[Nature Geosci](#)

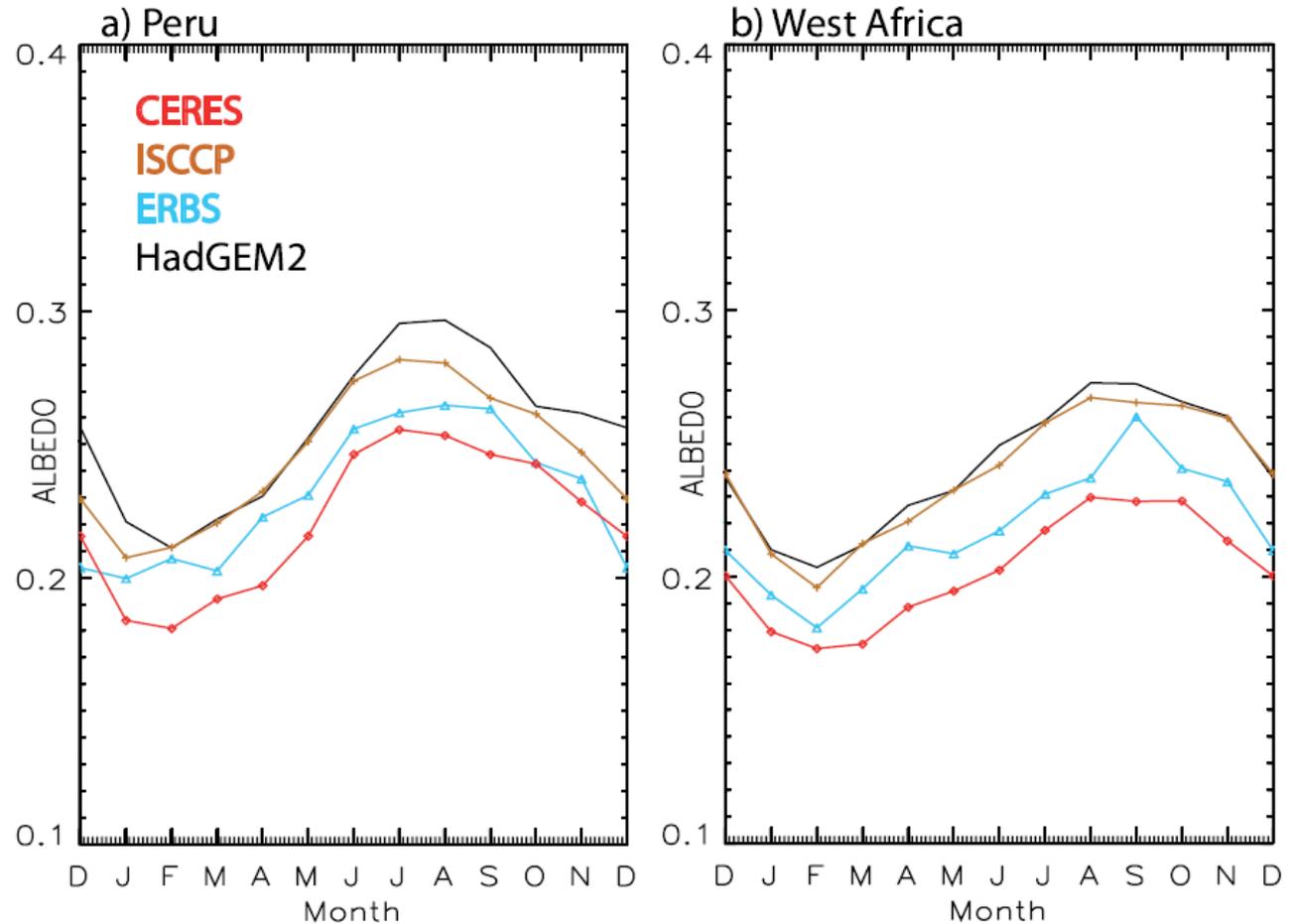
Spatial infilling of data gaps influences trends in surface temperature

(
[Cowtan & Way, 2013 QJRMS](#)) and ocean heat content (
(

[Lyman & Johnson](#)

[2014 J. Clim.](#))

Evaluating seasonal cycle in marine stratocumulus



Claire Barber